

APPENDIX
TO
LEARNING ABOUT ENERGY AND
PROCESSES OF CHANGE:
AN INVESTIGATION OF NOVEL ASPECTS
OF A CURRICULUM INTERVENTION

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Appendix 4.1

Teaching about physical, chemical and biological processes of change*

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ABSTRACT

My research is concerned with how children's ideas about the nature of processes of change develop when they use the curriculum material developed in the 'Teaching about energy and change' project. This addresses the fact that physical, chemical and biological changes depend on the Second Law of Thermodynamics, and therefore can be accounted for by only a few thermodynamic principles.

By interviewing children and teachers using the curriculum material as part of their Key Stage 3 science course, I investigated how the project's approach affects the way children talk about changes. I was particularly interested in examining the level of generality at which children see various changes as being similar and different, and whether matching real world situations to the abstract pictorial representations developed by the project helps in drawing their attention to the more generalised features of changes -both those they had met in lessons and those that were new to them.

In this paper I am presenting the design of one of the interviews used in the research, and the findings that emerge from the analysis of four instances of it. This interview entailed looking at energy flows and temperature differences in situations involving insulation and was carried out with pupils of 12-13 years of age.

BACKGROUND

The problem I have chosen to address in the PhD research* I have embarked on since January 1993, is one of great importance to science education, namely the teaching of energy. Energy is one of the most fundamental concepts of the Natural Sciences both because it is crucial to their application in Technology and even more because treated as an abstract conceptual framework it serves to interpret complex reality in a coherent way. Moreover, in recent years energy education has been expected to deliver both the specialist knowledge and enough civic understanding to guide informed decisions and effect changes in policies concerning environmental and ecological issues.

Despite, however, its importance for achieving scientific literacy, there is strong evidence world-wide that the concept of energy presents significant conceptual

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difficulties to pupils and teachers alike, difficulties which on many occasions result in a fundamentally incorrect understanding of the concept. This misunderstanding seems to arise in part from the way the word 'energy' is usually discussed in relation to the 'energy-crisis' as something (a fuel or a kind of fuel) which is in short supply and which is used or consumed for our benefit. Furthermore, in most school science courses today when energy is used to talk about processes of change it stands in for the cause of change -an approach which besides being erroneous suggests that energy gets used up. Thus, the concept of energy is made to cover both its main aspects, that is, being a conserved quantity which limits the possibilities of change, and 'fuel' (technically a source of free energy or negative entropy) which is destroyed, needs to be saved, and is a way of thinking about the direction of a possible change.

A way to resolve these difficulties in a teaching approach for energy which would build on children's ideas, following an evolving and not an unlearning process, and be relevant to their experience of life, is by addressing the fact that processes of physical and chemical change depend on the Second Law of Thermodynamics, that is, that the direction of change is that of decreasing order. In other words the suggestion/hypothesis I adopt (Ogborn, 1990) is that we can profit from the fact that children are already thinking about processes of change and prompt them to speak of the cause of change in a Second Law language where attention will be paid to differences; differences such as those between hot and cold, concentrated and dilute, pure and impure, squashed and spread out. The term 'differences' corresponds to the scientific concept of negative entropy -or free energy-, and the key idea is that differences drive change because differences tend to decrease -entropy tends to increase.

The great advantage of this approach is that it encapsulates the Second Law thinking without needing explicit reference to entropy or other Second Law ideas, and thus is capable of providing both a simple and intuitive starting point for talking about what makes things 'go' at the beginning of work at a secondary level, and a foundation for development of a Second Law account at a more advanced level.

Where does energy fit in this approach? Energy does not drive change, but sets the limits for the possibility of change. Thus, energy is introduced when we need to quantify change, when we need to compare the amounts of energy transferred from and to various kinds of systems. In this way, the more intuitive concept ('the something that is used up') will be introduced before the more difficult one ('the something that is conserved'), in an effort to make discussion in science classrooms about important matters like food, fuels, and life, more sensible and intelligible.

A FUNDED RESEARCH PROJECT - A PhD RESEARCH WAS BORN

A funded research project called 'Teaching about energy and change'* developed a set of classroom activities, resources, and in service training for teachers' materials about energy and processes of change based on the ideas discussed above. I witnessed and assisted this effort from its very first steps; as a consequence, the object of my research as well as the methodology stemmed from it.

One of the first difficulties the project had to tackle was how to show that a wide range of phenomena, from a hot cup of tea cooling to chemical reactions and even to processes involving life, which look so different and behave so differently, are essentially very similar in the sense that one only needs a few thermodynamic principles to understand them. Although the story about differences is more easily accessible than the conventional Second Law story, it still requires pupils to reason about real world situations in abstract terms. A way that was suggested to overcome this difficulty is by using pictorial representations to illustrate the idea of differences

* The 'Teaching about energy and change' project is based at the University of London, Institute of Education, Department of Science Education, and is run by Richard Boohan and Jon Ogborn. The project started in September 1992, and is funded by the Nuffield Foundation. The final pack of materials will be published at the end of the project in 1995.

(e.g., of concentration of energy and matter) getting evened out in spontaneous changes or maintained in steady state systems. A set of pictures illustrating mixing, diffusing, heat flow, melting, boiling, and chemical change were prepared and tried out in schools. Abstract pictures that represent the differences in the arrangement of energy and in the arrangement of matter, as these also constitute causes of change, were later also developed. The emphasis is on pupils becoming familiar with the ideas behind the representations through using the materials over the long term and by relating them to real world prototypical situations, so that they in turn help them to think about less familiar real world situations. So, representations are not by themselves a goal of this teaching approach, but constitute a tool, which may help pupils to abstract the story about differences from a variety of processes of change. At the highest level we would want the children to be able to abstract further from the different kinds of representations and reach a broader understanding -to see how the bits fit together and are used in an energy language.

In my research I set out to investigate how children's ideas about processes of change and energy develop as a result of this teaching approach.

ABOUT THE RESEARCH

The research was carried out in two phases. The first phase had an exploratory character and was mainly informed by the needs of the project to investigate the way children make sense and use abstract pictorial representations. In the second phase the influence of the novel teaching approach -developed by the 'Teaching about energy and change' project- on children's ideas about processes of change and their causes was monitored more systematically and over a longer period.

PHASE 1: EXPLORING AND DEVELOPING THE REPRESENTATIONS

At the time the first phase of my research took place, the project was developing the idea of using abstract pictorial representations of changes in order to help pupils focus on the more generalized features of the changes, and the concern was to find out first how children would make sense of these abstract pictures and second how these could be used in the classroom. The interviews, subsequently conducted by Richard Boohan and myself, were designed to investigate the first of these two concerns. They also endeavoured to detect any influence the first teaching attempts - which were taking place concurrently- might have had on children's perceptions of processes of change and their causes. The structure of the interviews, on the other hand, also reflected the principles of the new teaching approach, namely that of looking for similarities between changes which are apparently very different. We conducted fourteen interviews in total, with pupils at different Key Stage 3 and 4 levels, that is, with pupils in the age range 11-15 years old.

PHASE 2: MAIN RESEARCH - LOOKING FOR LONGER TERM EFFECTS

To meet my research objective, that is, to evaluate the application of the project's ideas, I had to make sure that I could monitor in a systematic way how children's conceptions about change develop, in relation to the objectives set by the project, over a long time. I therefore arranged my fieldwork, which took place during the academic year 1993-94, in a secondary school, which had agreed to integrate the teaching material produced by the 'Teaching about energy and change' project in their Key Stage 3 science curriculum. The school is an inner-city London comprehensive with pupils in mixed-ability classes.

I worked with one Year 7 and one Year 8 class, that is, with 11-13 year old pupils, over a period of eight months. In this school the science curriculum is organized into a number of topics; for each class, I attended virtually all the lessons

for three topics. For Year 7 the three topics were 'Water', 'Air' / 'Materials' and 'Life', while for Year 8 these were 'Substances', 'Energy' and 'Health'. These topics were chosen as they covered ideas especially important to the work of the project. Processes of dissolving, mixing, crystallizing, diffusion, but also changes of state, energy flows and chemical changes were examined in the classroom using the materials and activities produced by the project. These materials and class activities for Year 7 invite pupils to pay attention to differences in temperature and to identifying matter 'spreading out' and 'bunching together', mixing and 'un-mixing'; to pay attention to differences in temperature, to the nature of a substance, to the nature of changes of state, and finally to processes that happen easily but are more difficult to reverse. For Year 8 they talk about changes and energy flow caused by temperature differences, they interpret physical and chemical changes in terms of particles and they pay attention to stores of concentrated energy.

I kept detailed observational notes on each lesson attended (sixty four lessons in total - forty one from Year 7 and twenty three from Year 8). In addition, at the beginning and at the end of each of these three learning sequences I conducted interviews with all the pupils of each class in groups of four. The interviews were designed to elicit the pupils' ideas and abstract thinking about change, in the course of two activities. In the first activity pupils were asked to put a set of situations into groups of similar changes and in the second to match the situations to abstract pictures and explain their choices. The set of situations and the set of abstract pictures used were different for every interview and depended on the topic the pupils had previously completed.

I also conducted interviews with the teachers who used the materials in order to find out how accessible and useful these teaching materials had been to them, what problems, if any, the materials had presented them, how easy or difficult their integration in schemes of work had been, etc..

CURRENT WORK: ANALYSIS OF DATA COLLECTED DURING PHASE 1

Since September 1994 I have been working on the analysis of my data. My current aim is to analyze the interviews of the first phase of my research. I expect that their analysis will further guide the analysis of the interviews of my main research (Phase 2). The observation notes from the lessons I attended, as well as the copies of the pupils' written assignments are also going to inform the analysis of the interviews of my main research as they will provide the background material for the analysis. They will help me in addressing the question of whether and how the experiences that children had in the classroom influenced the development and expression of their ideas about processes of change and their causes.

In the rest of my paper I will be concerned with the Phase 1 interviews and more specifically with the findings that emerge from the analysis of four of them.

YEAR 8 INTERVIEWS: DESIGN OF THE TASK

I will be concerned here with the four interviews carried out with pupils from a mixed-ability Year 8 class in an inner-city London comprehensive. The interviews took place after children had completed a topic on 'Energy' in their science classrooms, which had included ideas from the 'differences story' specially adapted for Year 8 pupils. The pupils were interviewed in groups of four and had not previously been introduced to the abstract pictures used in the interviews.

The interview tasks concerned thermal changes and entailed looking at energy flows and temperature differences in situations involving insulation. The situations used covered a variety of different objects -each in an insulated and a non-insulated instance-, and of different insulators, as well as a range of temperatures with the objects below, above or at the temperature of the surroundings. The following eight situations were chosen:

situations	non-insulated	insulated
• hot chocolate left in a room	in a cup	in a vacuum flask
• cold lemonade in a warm room	in a glass	in a vacuum flask
• frozen food	left on a table	wrapped in newspaper
• coins at room temperature	left on a table	wrapped in a woollen bag
• hot water tank	without insulation	with insulation
• snowman on a freezing day	by itself	wrapped in a coat
• sun shining on a house	poorly insulated house	well insulated house
• water pipes on a cold day in winter	without insulation	with insulation

Each interview lasted forty five minutes approximately and consisted of three activities.

In the first activity we gave the pupils the eight insulated examples, and asked them to put them into groups of similar kinds of changes, and then to explain their reasons for the groupings.

In the second activity, ('the teaching activity'), we introduced the pupils to the abstract representations and gave them a chance to try out whether they had understood the conventions. This activity was in two parts. First the temperature changes of a metal block were considered in a 'story', in which the metal block was first put in an oven, then taken out and left in a room, then put in a fridge and finally left in the room; the analogous changes for an insulated metal block, together with the rates of these changes were also examined in the same discussion. In the second part, abstract pictures of energy flow were introduced to the pupils and the conventions were explained: that the shading represents the concentration of energy, that is the temperature, so if the square in the centre is darker than its surroundings, it is warmer, and if it is lighter, it is cooler; that arrows show energy flow into or out of the object, and that their size indicates the rate at which the energy is flowing. Then pupils were asked to choose the pictures they thought best represented what was happening at various stages of the story; in this activity their choices were discussed and corrected.

Finally in the third activity we gave them the eight situations again, only this time paired with each non-insulated situation, and asked them to match them in turn to one out of a total of nine pairs of abstract pictures, shown in appendix 1, and to explain their reasons. If a situation was matched to a representation which had previously been matched to another situation, the interviewer asked for similarities and differences between the two situations. What we were investigating was whether the pictorial representations succeeded in drawing children's attention to the essential features of the processes of change, and furthermore whether they helped them see similarities between different processes based on these essential features.

Given the above, pupils' talk during the third activity of the interviews holds a special interest. In the remaining part of this paper I include a synthesis of the qualitative analyses of the four Year 8 interviews for this last activity. I also include the systemic network on the basis of which the analysis was conducted (appendix 2).

SYNTHESIS OF ANALYSES OF FOUR YEAR 8 INTERVIEWS FOR ACTIVITY 3

Activity 3: Matching situations to abstract representations of thermal energy flows

Matching attempt

Most of the pupils in all four groups were able to give reasons for making their choices of representations. From the reasons given -counting each time one for the non-insulated and one for the insulated situation- all together fifty seven, independently of whether the match was successful or not, only seven were inconsistent with the choice of picture. The extent to which these reasons were fully developed and clear varied from group to group, so did the level of agreement among

the pupils concerning the choice of representation that best depicted the change for each of the situations. In the case of agreement pupils' interactions seemed to favour the exchange of short and incomplete explanations which although holding less interest led sometimes to the formation of a more coherent and thorough overall argument. Disagreement led to more pupils contributing to the discussion, either offering their reasons for an alternative match, or raising objections concerning a particular choice of picture and its relevant justification, and thus having more potential to stimulate more extended and causal reasonings. That is not to say that all disagreements led to interesting discussions; many were limited to pupils' independently giving alternative descriptions of the change, without defending them or juxtaposing them to the previously expressed ones. It is interesting, however, that in the cases where disagreement led to a change of choice or to a consensual choice of match, this on the whole favoured the most reasonable / correct match of the defended alternatives.

On the whole, there were many successful matching attempts. However, good discussion could arise from disagreements or failures.

Temperature differences

In all groups pupils paid attention to the temperatures of the system and its surroundings. They more often identified the temperature of the system explicitly, while that of the surroundings received less consideration -performance varied across the groups. Both temperatures were usually referred to in the generalized terms 'hot', 'cold', etc.. This tells us that when pupils are reasoning about or with these temperatures, they can achieve a level of abstraction at which two different systems - for example, a snowman and a lemonade in the fridge- can be both seen as having similar temperatures -'they are both cold'-, and thus can be expected to behave similarly in similar thermal exchanges. Furthermore, temperatures can be expressed in either absolute terms or relative terms. In other words, the temperatures of the system and of its surroundings can be characterized either on their own, e.g. 'hot', 'cold' etc., or in relation to each other, e.g. 'hotter', 'colder', etc.. The temperature of the system can also be expressed in terms relative to its previous state, and this seems to prevail more in the explanations in which there is no attention paid to the surroundings. The use of relative versus absolute terms for the expression of the temperature of the system and/or its surroundings varied among the groups and has to be considered in connection with the fact that the situations presented to the pupils included absolute temperature characterizations in their names (e.g. 'hot chocolate left in a room').

One more point has to be raised here. I noticed that the temperature of the surroundings is often -but not always or exclusively- missing from the explanations of the changes where the system can be imagined or is said to be found in a room. A possible explanation could be that pupils take it as obvious that the temperature of a room, unless otherwise stated, is 'normal' -'room temperature'- so they don't need to mention it.

In many of the explanations there was some more or less explicit reference to a temperature difference or an absence of a temperature difference between the system and its surroundings. The expression of either the temperature of the system or that of its surroundings in terms relative to one another I take as evidence of an identification -explicit in this case- of a temperature difference between the system and its surroundings. I also make the same identification for the use of a temperature contrast in an explanation, for example:

"But this snowman is with insulation so it's warm inside, so the cold from the outside is coming into the inside somehow."

These temperature contrasts / differences or the absence of them are more or less seen as causally related to change or absence of change of the system and further to the existence or absence of an energy flow. For example,

"But they [the coins -the system] can't go warm, they [the system and its surroundings] are both the same temperature."

On the whole, attention is paid to temperature, but not always to temperature differences. The idea of a temperature difference is often expressed informally or implicitly, for example through contrasts of temperatures.

Flows

In most of their explanations pupils referred to a flow or its absence. This might be a flow of energy, a flow of 'heat', a flow of 'temperature' / 'hot temperature' / 'room temperature', a flow of 'air' / 'hot air', even to a flow of 'cold' / 'coldness' twice -as the complementary entity of 'hot' / 'hotness'.

However, the explanations did not very often include an explicit reference to a cause for this flow. In the instances where they did, perceived causes -acting sometimes also as agents of the flows- were: the temperature contrast / difference between the system and its surroundings, the temperature -'hotness'- of the system, the existence of insulation, and the absence of insulation. The existence of insulation was more particularly related to flows of 'heat' or 'hot air'. For the absence of a flow, the identified cause seems to be a bit more straightforward; this was either the absence of a temperature difference between the system and its surroundings or the existence of insulation.

The effects of the flows were also only rarely mentioned. The identified flows were hardly ever said to cause change in the temperature of the system or of its surroundings, by all but one group.

Only the explanations in two out of the four interviews included references to the rate of flow. Moreover, these references seem to appear mainly in the explanations of the insulated situations and seem to explicitly relate the rate of flow to the existence of the insulation. The rate of flow can also be seen to be related to the temperature -'hotness'- of the system and/or to the temperature difference between the system and its surroundings. It is worth noticing that some pupils explicitly associated the rate of the energy/heat flow in a change with the size of the arrow -standing for the thermal flow- in its abstract representation, and/or that they seem to speak about it as if it were equivalent to the amount of energy/heat flow:

"... the small arrow is showing that only a little bit of heat is escaping, slowly."

Generally, the thermal changes used in the interviews were often seen by the pupils as involving a flow, but this might be a flow of 'temperature' as well as a flow of energy or 'heat'. The absence of a flow in other cases was correctly understood as due to lack of temperature differences or to presence of insulation.

Energy

The term 'energy' did not appear with the same frequency in all interviews; its occurrence varied significantly across groups. More specifically, in one interview the word 'energy' did not appear at all in pupils' explanations while in another one it was used so easily and extensively that seems to have made the use of the more popular term 'heat' unnecessary.

'Heat' and 'temperature' were often used in place of 'energy' without discrimination. On the whole energy was perceived as a localized amount-like

substance which can move/flow; sometimes it could be more explicitly thought of as residing in hot things and as carried by air.

"There's the hot water tank has no insulation, it's really hot, so it's going to pass energy to the room -a really lot of energy."

Insulation

By all four groups of children, when insulation was identified, it was seen as causally related to the change or absence of change of the system. As has also often been noted in similar investigations, insulation was either seen as the cause for the absence of change in the system, blocking any kind of flow, or as determining the rate of flow amount of energy flowing. However, in not a few explanations it was perceived as actively making the system warm/hot, perhaps to the point of generating 'heat':

"But the cold doesn't escape, the insulation makes the lemonade warmer because the energy..."

The insulating material seems to be an important factor in deciding what the effect of the insulation might be. Each insulating material seems to behave differently as to whether it 'blocks', 'permits' or 'causes' a temperature change in the system, depending on the everyday experience the pupils have with it. While the vacuum flask, for example, acts as a blocking device for energy transfers:

"But the vacuum flask keeps the heat into it. So the drink -the hot chocolate- is staying the same, it is still going to be hot because of the insulation of the vacuum flask."

"The cold lemonade in the vacuum flask doesn't do nothing because it has insulation."

the newspaper acts either as a generator of 'heat':

"...the frozen food is wrapped up in a newspaper, the newspaper is like the insulation -it makes the food warmer."

or as a 'bad' insulator permitting energy flows:

"...the newspaper is not that powerful so the room temperature will go slowly into the thingy... the newspaper wrapping into the food.... It's not good insulation."

Another factor that influences what pupils perceive as the effects of insulation is the identified temperature contrasts or differences between the system and its surroundings. In some cases it happens that the identified temperature contrasts or the absence of them dictate a certain kind of flow or its absence, while a consideration of the existence of the insulation would suggest otherwise. In these cases, the pupils more often seem to decide correctly about the existence or not of the flow and about its direction based on what they perceive as the temperature gradient between the system and its surroundings.

Pupil 1: *"... and the woollen bag the heat should be going in, but it is not going to be coming out so the heat is getting into there."*

Pupil 2: *"But they can't go warm, they are both the same temperature."*

A third factor can be the actual 'hotness' of the system. When the system is considered to be very hot, the insulation becomes permeable:

"This is like a hot water tank, isn't it. [...] It's really, really hot. So it is going to go through the insulation."

And, furthermore, the hotter the system, the more heat manages to flow through the insulation:

"That's really hot and that is not as hot. So it won't come out as much."

Summarizing the above points, insulation is correctly considered in relation to the temperature change of the system. However, it is not only seen as determining the rate of the thermal flows but also their existence and direction.

Similarities and differences identified between two situations

In only two out of the four interviews were children asked to identify similarities and differences between situations. These were changes matched by the pupils to the same representation and on that basis the interviewer asked them whether they perceived any similarities or differences between them.

Due to lack of time the sample of such responses is overall very small, so no valid general claims can be made. However, my first impression was that when pupils identified similarities and differences between two changes they mainly reasoned at a general level. For example, they justified similarities on the basis of two systems having the same temperatures -expressed in generalized terms- in the 'before' and/or 'after' instances of the change. The differences identified concerned mainly the insulated situations and seemed to be about the insulating materials and their effects.

Use of the pictorial representations

In all four groups no pupil seemed to discuss or raise issues about the pictures used in the activity as abstract representations of the thermal changes. Moreover, as I mentioned before, from the fifty seven explanations given for the matches, only seven were inconsistent with the choice of pictures. However, significant actual verbal reference to the representations and their conventions appeared in the explanations of only one group. In all these references the conventions mentioned or implied were interpreted correctly. Most of them concerned the convention of the arrow (its size and/or its direction) in the representation. The size of the arrow was seen as an indicator of the rate of the flow; its direction in one case seemed to influence the explanation given for the change.

But, no mention of the representations does not mean no use of them. On the contrary, it could mean that there is no need to mention them; that it is mainly uncertainty about the change that makes the pupil look for clues in the representations and in the structure of the task.

On the whole, pupils' explanations suggest that they had no problem in interpreting the conventions of the abstract pictorial representations of thermal changes and that they successfully used them when reasoning about their choices.

CONCLUDING REMARKS - FUTURE WORK

The findings reported in this paper are only preliminary. The analysis will be extended to interviews with Year 9 and Year 10 children and is going to cover other types of changes, for example chemical changes involving abstract pictures of

particles. The systemic network I am using (see appendix 2) will be developed and refined in the process, as it will be constantly tested on new data.

In the interviews of my main research, I will also be looking for the long-term effects the teaching approach developed by the 'Teaching about energy and change' project may have had on children's reasoning about physical, chemical and biological processes of change.

Finally, in analyzing the interviews I had with the teachers I will be looking for data on the use of the materials in the classroom, as well as on the scope for integrating them in a secondary school's science curriculum.

REFERENCES

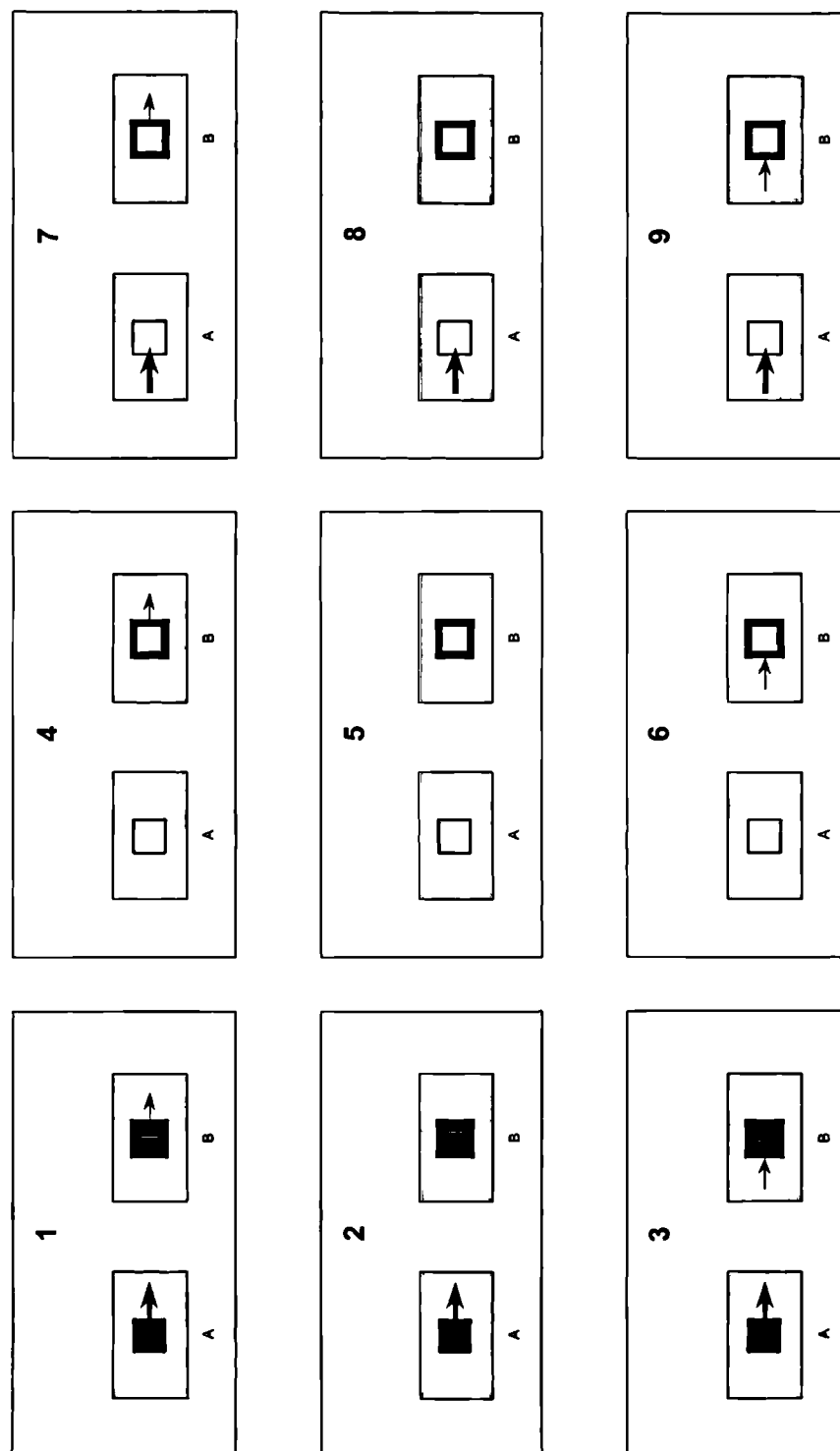
Ogborn, J. (1990) 'Energy, change, difference and danger' *School Science Review*, 72, 259, pp 81-85.

Stylianidou, F. (1993) 'The concept of energy and its teaching' in Lijnse P.L. (ed.) *European research in science education: Proceedings of the first Ph.D. Summerschool*, Utrecht: CD-b Press, Centrum voor b-Didaktiek, pp 255-258

APPENDIX 1

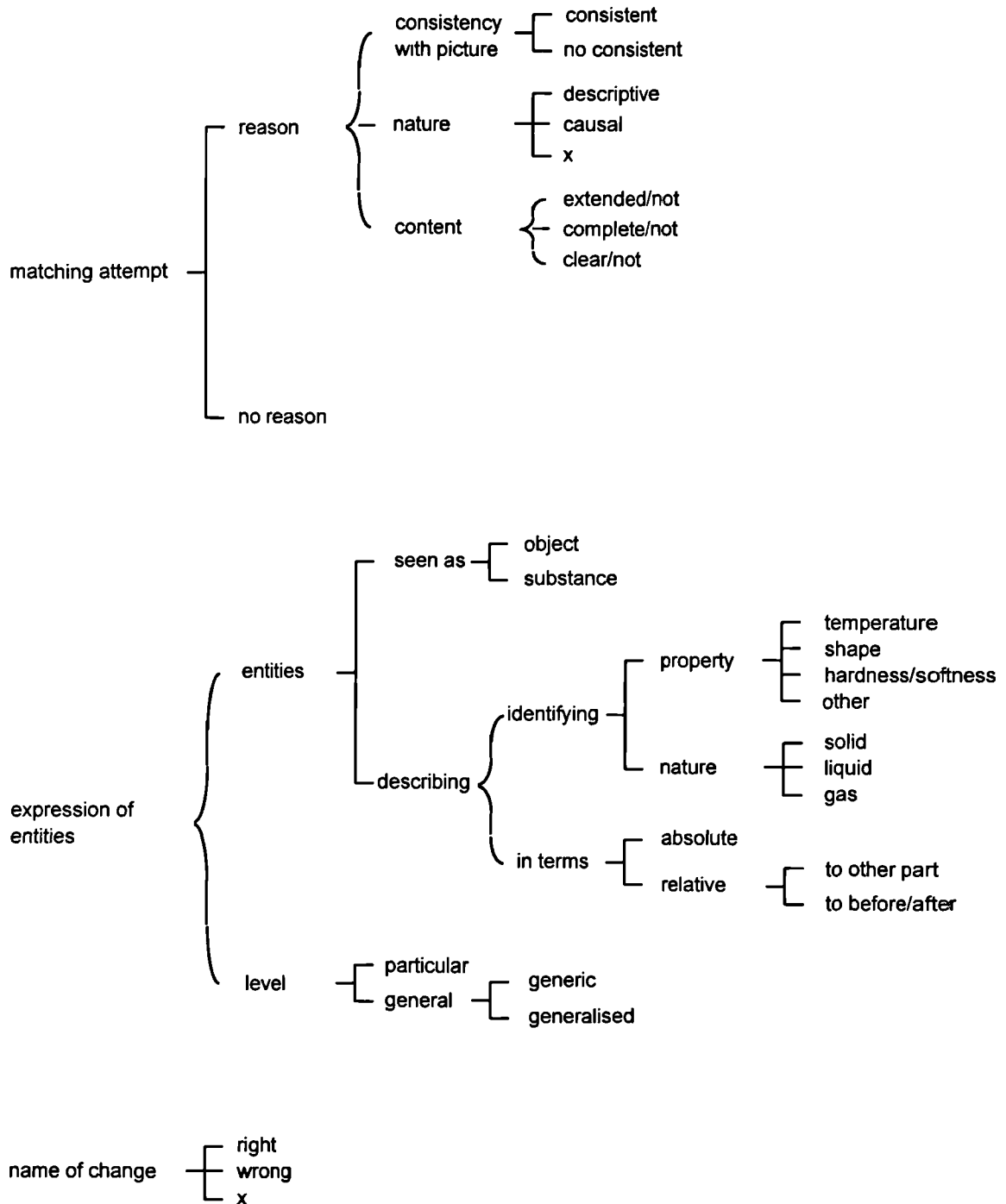
ABSTRACT PICTURES FOR YEAR 8 INTERVIEWS

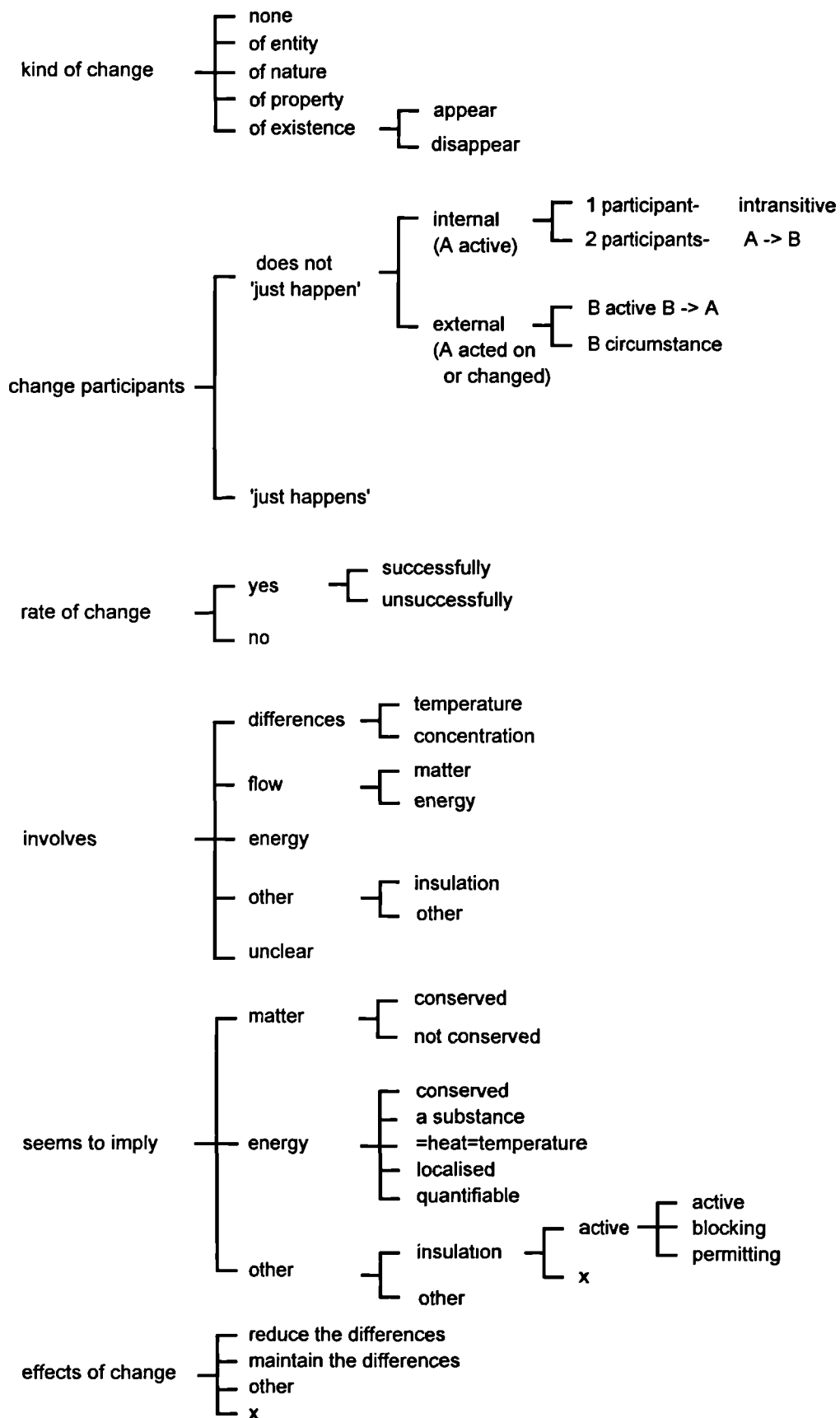
Activity 3: Matching situations to abstract representations



APPENDIX 2

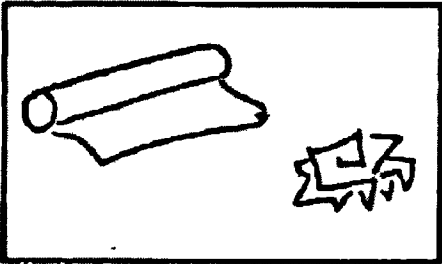
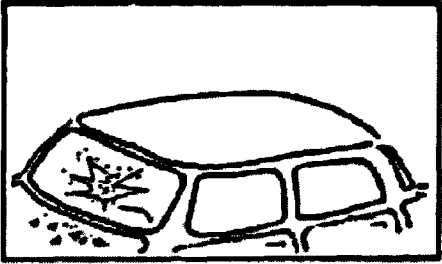
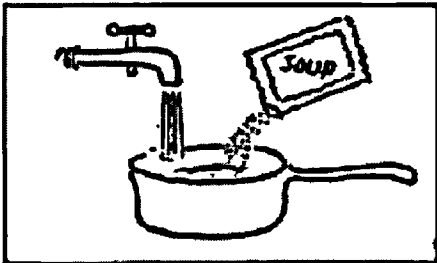
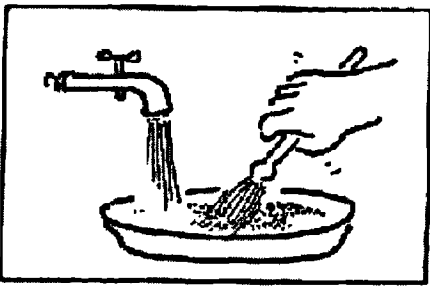
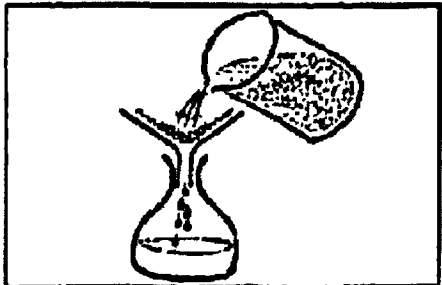
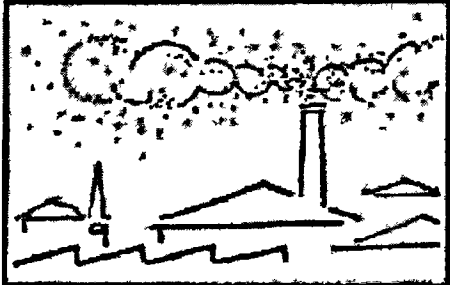
Systemic network for analysis of Phase 1 Interviews



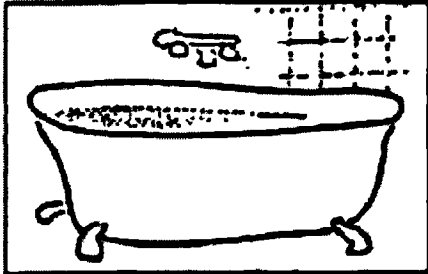


Appendix 5.1

Situations used in interviews with pupils

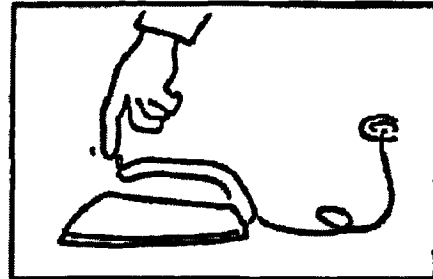
<p style="text-align: center;">M1</p>  <p style="text-align: center;">metal foil being crumpled up</p>	<p style="text-align: center;">M2</p>  <p style="text-align: center;">a car windscreen being shattered</p>
<p style="text-align: center;">M3</p>  <p style="text-align: center;">making soup out of powder soup and water</p>	<p style="text-align: center;">M4</p>  <p style="text-align: center;">cleaning a paint brush in water</p>
<p style="text-align: center;">M5</p>  <p style="text-align: center;">purifying water</p>	<p style="text-align: center;">M6</p>  <p style="text-align: center;">smoke filling the air over a city</p>

E1



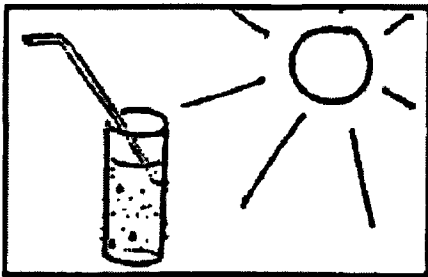
a hot bath cools down

E2



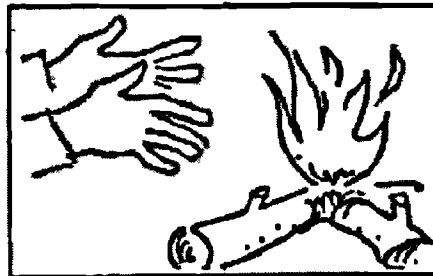
an electric iron cools down
after being switched off

E3



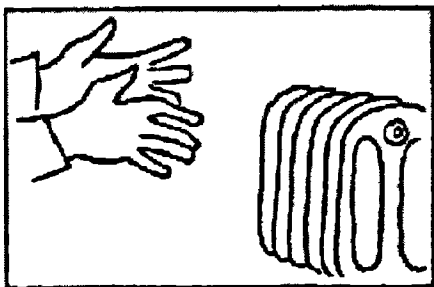
a cold drink left out in the sun

E4



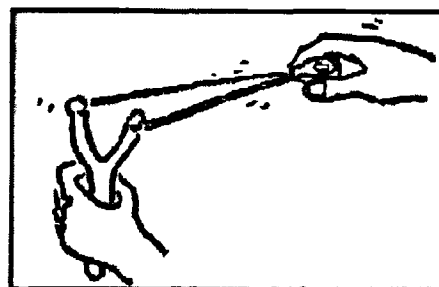
warming your hands near the fire

E4b


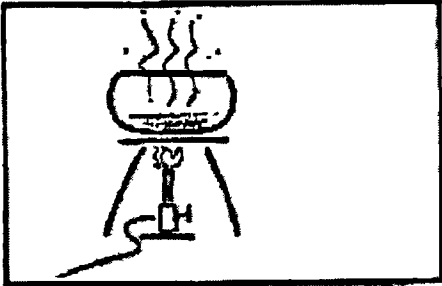
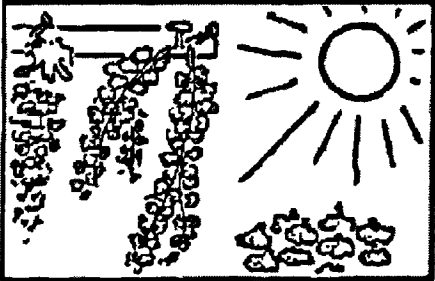
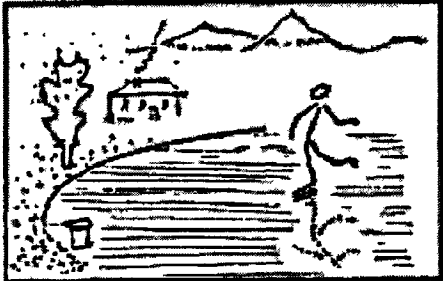
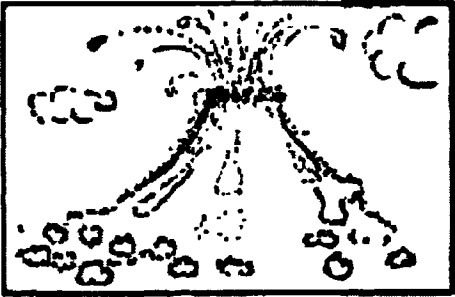
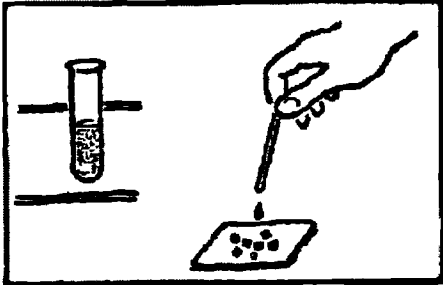


warming your hands by the radiator

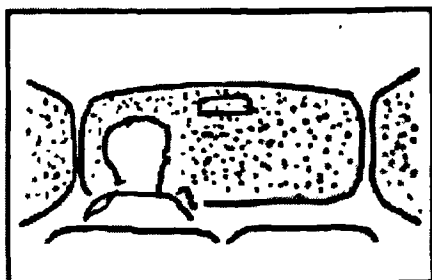
E5



pulling a catapult to get ready
to fire a stone

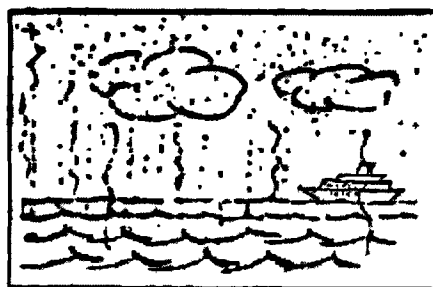
<p>PH1</p>  <p>scent or after-shave evaporating from the skin</p>	<p>PH2</p>  <p>getting salt by evaporating salt solution</p>
<p>PH3</p>  <p>fruit drying in the sun</p>	<p>PH4</p>  <p>ice forming on a pond</p>
<p>PH5</p>  <p>hot lava from a volcano turns solid</p>	<p>PH6</p>  <p>crystals forming in copper sulphate solution as it cools</p>

PH7



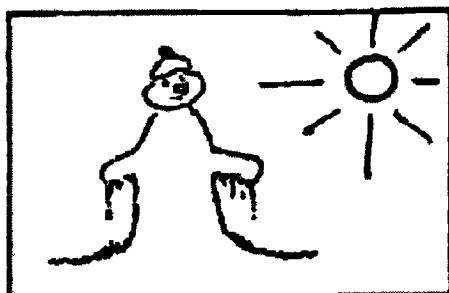
the windows of the car misting up
on a very cold day

PH8



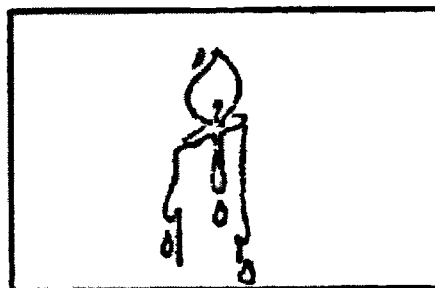
water vapour forms clouds
and it rains

PH9



a snowman melting

PH10



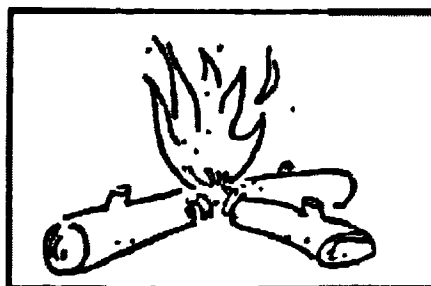
melting wax

CH1



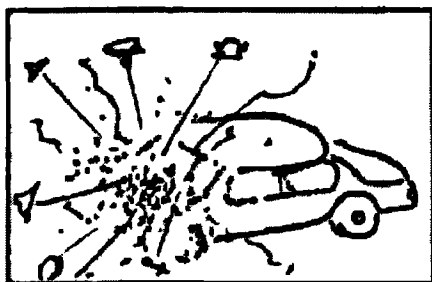
acid rain eroding a stone statue

CH2



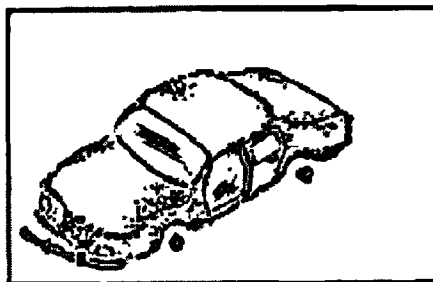
wood burning

CH3



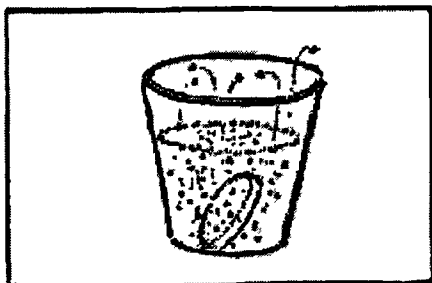
an explosion

CH4



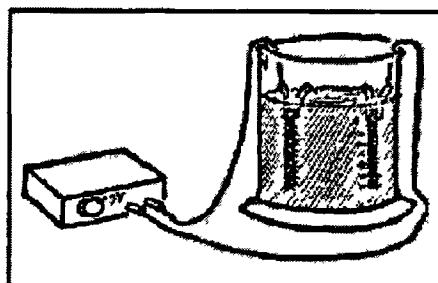
a car rusting

CH5



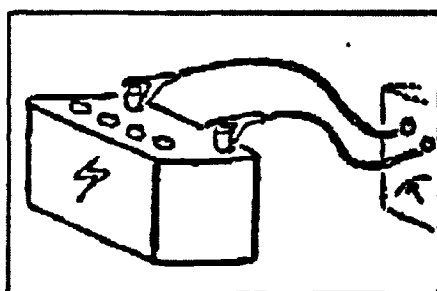
putting Alka Seltzer in water

CH6

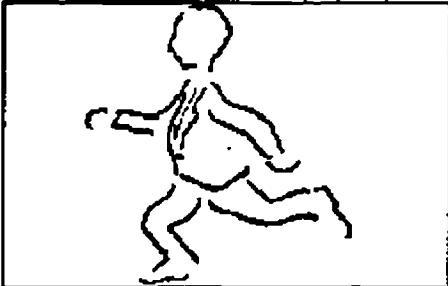


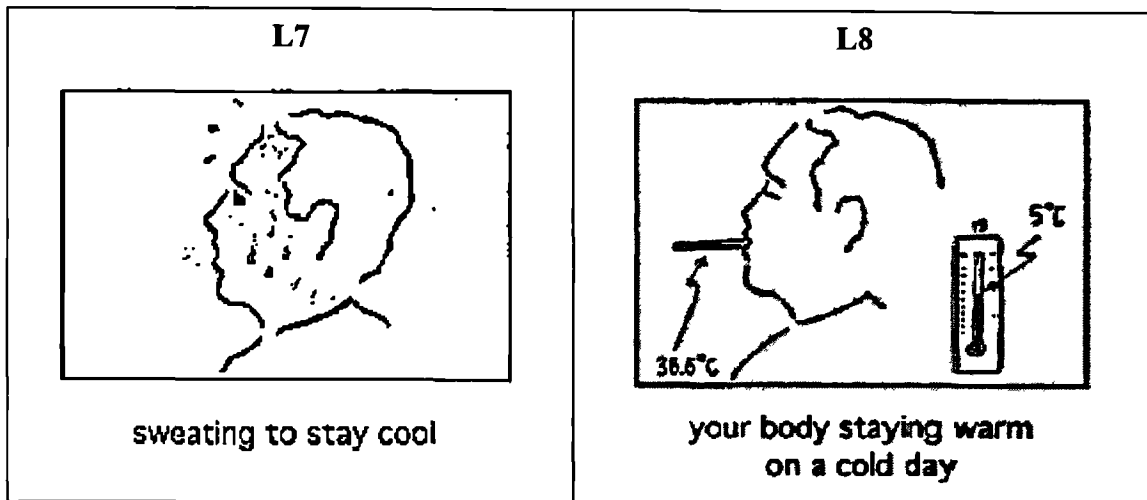
extracting copper by electrolysing
copper sulphate solution

CH7



charging a car battery

<p>L1</p>  <p>a plant growing</p>	<p>L2</p>  <p>your hair growing</p>
<p>L3</p>  <p>a baby's bones growing</p>	<p>L4</p>  <p>your body making extra fat</p>
<p>L5</p>  <p>digesting food</p>	<p>L6</p>  <p>running and using up food</p>



Appendix 5.2

Interview schedule: SC Y7 First

Write down pupils names in order from left to right.

Explain to pupils what will happen. They will look for similar changes.

Task 1: Linking similar changes

- Lay out 12 situations. Interviewer reads through text on cards and tells them to think about what is changing in each one. She asks them to pick one change and then to look at all the others and find the one they think is most similar. They can link them with a line on the poster and write their reason on the line. Then they look for another change (until they exhaust all situations) and repeat the same procedure.
- After each linking ask about reasons. Then explain that we will look at some examples in more detail.
- Write down letters of situations on poster paper before removing them.
- Situations chosen:
 - a scent or after-shave evaporating from the skin (evaporation – PH1)
 - b ice forming on a pond (freezing – PH4)
 - c a cold drink left out in the sun (warming – E3)
 - d acid rain eroding a stone statue (dissolving – CH1)
 - e hot lava from a volcano turns solid (freezing – PH5)
 - f making soup out of powder soup and water (dissolving – M3)
 - g fruit drying in the sun (evaporation – PH3)
 - h a plant growing (order – L1)
 - i a car windscreen being shattered (breaking – M2)
 - j wood burning (CH2)
 - k digesting food (disorder – L5)
 - l a hot bath cools down (cooling – E1)

Task 2: Looking at some changes in detail

- Interviewer has selected the following 4 pairs of situations:
 - hot bath cools down - a cold drink left out in the sun
 - ice forming on a pond - hot lava from a volcano turns solid
 - wood burning - plant growing
 - making soup out of powder soup and water - acid rain eroding a stone statue
- Interviewer lays down one of the above pairs as well as twenty sentences written on separate cards. She reads out the sentences. She asks each pupil in turn from left to right to pick one sentence which is true for both changes (similarity) and put it in between them. Interviewer asks them to explain their choice as well as for any disagreement.
- Then ask each pupil in turn from left to right to pick one sentence which is true for only one of the changes and put it underneath that change. Interviewer asks them to explain their choice as well as for any disagreement.
- If time allows ask them to pick one sentence that is completely wrong for both changes.
- Repeat for other 3 pairs of situations.

Key sentences for Y7 and Y8 First (A) Interviews

something 'spreads out'

something 'bunches' together

something is mixing

something is unmixing

something gets warmer

something gets cooler

temperature evens out

something becomes solid

something becomes liquid

something becomes gas

it makes a new substance

substances stay the same

it happens by itself

someone makes it happen

something disappears
or gets used up

energy 'spreads out'

temperature stays the same

a substance changes

it is easy to reverse the change

energy becomes concentrated
in something

Appendix 5.3

Interview schedule: SC Y7 Second

Write down pupils names in order from left to right.

Explain to pupils what will happen. They will look for similar changes.

Task 1: Linking similar changes

- Lay out 8 situations clockwise from **a** -at the top of the poster paper- to **h**. Interviewer reads through text on cards and tells pupils to think about what is changing in each one. She picks change **a** and then tells the children to look at all the others and find the one they think is most similar to it. They can link them with an arrow on the poster starting from the one the interviewer picks to the one they find as similar to it. Then the interviewer picks the next -going clockwise- change which doesn't have arrows ending at it and the pupils again look for the best similar change among all the others. The same procedure is repeated for the remaining changes. The task should last approximately 10 minutes. If there is left time the interviewer may ask children to think also about the situations she skipped in the first round.
- After each linking ask about reasons. Then explain that they will look at some examples in more detail in the second task.
- Write down letters of situations on poster paper before removing them.
- Situations chosen:
 - a** crystals forming in copper sulphate solution as it cools (crystallising – PH6)
 - b** cleaning a paint brush in water (dissolving – M4)
 - c** the windows of the car misting up on a very cold day (condensation – PH7)
 - d** purifying water ('unmixing' – M5)
 - e** your hair growing (order – L2)
 - f** warming your hands near the fire (warming – E4)
 - g** an explosion (CH3)
 - h** an electric iron cools down after being switched off (cooling – E2)

Task 2: Matching situations to representations

- On an other poster paper interviewer lays down 7 representations in three groups and goes over with the pupils what each of the representations shows. They will need to match situations to these pictures.
- Each pupil is given 7 cards with numbers 1-7 on them. Explain that these are to be used to show what they think other pupils will choose.
- Give first situation (a) to first pupil from left.
- Before putting this next to representation, others pupils should put chosen cards face-down.
- Other pupils show cards.
- Interviewer reads out numbers to record on tape - pupil matching situation first, then the other three in order from left to right.
- Ask pupil why the representation was chosen.
If no pupil disagrees, move on.

If one other pupil disagrees, ask that pupil for a reason.

If more than one disagrees, open it to all to give reasons.

Does (first) pupil want to change mind or leave it where it is? (No reason needed.)

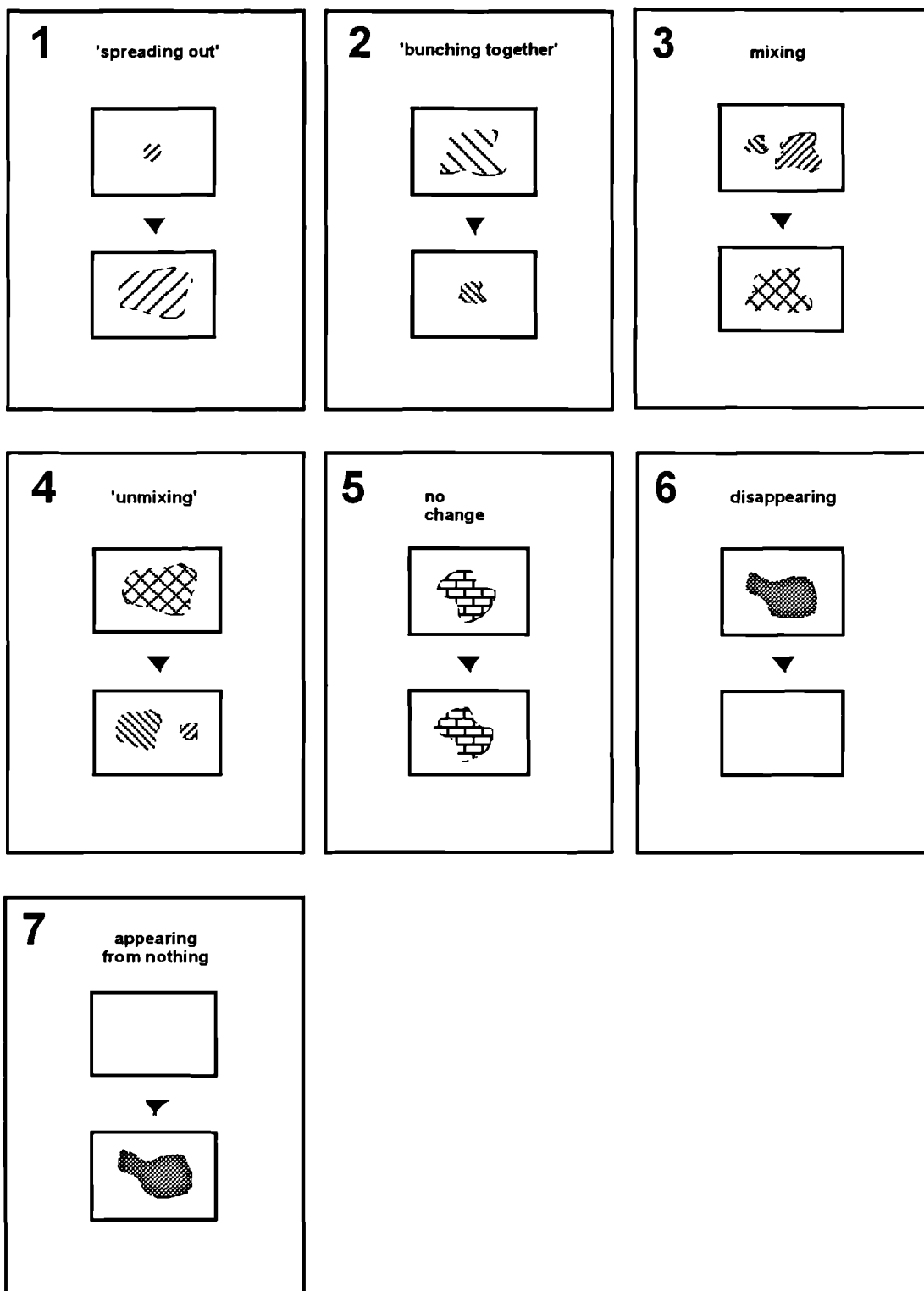
- If situation is matched to a representation which already has another situation, interviewer can ask:
You have matched these to the same picture. How are these situations similar?
Are there any differences between these situations?
- Interviewer can also ask for similarities and differences for situations put on the same 'line' group or on the same 'row' group.
- Repeat for the other situations (in order b-h) until all done.

Task 3: Comparing situations

- Interviewer may also want to ask for similarities and differences for the following pairs of situations:
 e-c your hair growing - the windows of the car misting up on a very cold day
 b-g cleaning a paint brush in water - an explosion
 a-d crystals forming in copper sulphate solutions as it cools - purifying water
- If there is time, after each pair of situations is examined / discussed for similarities and differences, the interviewer provides cards with sentences and asks pupils whether they think these are true for both or for one of the situations under examination. The sentences to discuss are:
someone makes it happen
it happens by itself
it is easy to reverse the change

energy 'spreads out'
energy becomes concentrated in something

Abstract pictures for Y7 Second (B) Interview



Appendix 5.4

Interview schedule: SC Y7 Third

Write down pupils names in order from left to right.

Explain to pupils what will happen. They will look for similar changes.

Task 1: Linking similar changes

- Lay out 8 situations clockwise from **a** -at the top of the poster paper- to **h**. Interviewer reads through text on cards and tells pupils to think about what is changing in each one. She picks change **a** and then tells the children to look at all the others and find the one they think is most similar to it. They can link them with an arrow on the poster starting from the one the interviewer picks to the one they find as similar to it. Then the interviewer picks the next -going clockwise- change which doesn't have arrows ending at it and the pupils again look for the best similar change among all the others. The same procedure is repeated for the remaining changes. The task should last approximately 10 minutes. If there is left time the interviewer may ask children to think also about the situations she skipped in the first round.
- After each linking ask about reasons. Then explain that they will look at some examples in more detail in the second task.
- Write down letters of situations on poster paper before removing them.
- Situations chosen:
 - a** smoke filling the air (matter 'spreads out' - M6)
 - b** a cold drink left out in the sun (warming - E3)
 - c** water vapour forms clouds (condensation, change of state - PH8)
 - d** melting wax (change of state - PH10)
 - e** wood burning (CH2)
 - f** your body staying warm on a cold day (steady state - L8)
 - g** getting salt by evaporating salt solution (crystallising, change of state - PH2)
 - h** warming your hands by the radiator (warming - E4)

Task 2: Matching situations to representations

- On an other poster paper interviewer lays down 7 representations in a matrix format (1-4 horizontally and A-C vertically):

	1. difference in temperature disappears	2. no change	3. difference in temperature appears	4. difference in temperature is maintained
A. 'spreading out'				
B. no change				
C. 'bunching together'				

and goes over with the pupils what each of the representations shows. They will need to match situations to these pictures.

- Each pupil is given 7 cards with numbers 1-4 and letters A-C on them. Explain that these are to be used to show what they think other pupils will choose.
- Give first situation (**a**) to first pupil from left.
- Before putting this next to representation, others pupils should put chosen cards face-down.
- Other pupils show cards.
- Interviewer reads out numbers to record on tape - pupil matching situation first, then the other three in order from left to right.
- Ask pupil why the representation was chosen.
If no pupil disagrees, move on.
If one other pupil disagrees, ask that pupil for a reason.
If more than one disagrees, open it to all to give reasons.

Does (first) pupil want to change mind or leave it where it is? (No reason needed.)

- If situation is matched to a representation which already has another situation, interviewer can ask:
You have matched these to the same picture. How are these situations similar?
Are there any differences between these situations?
- Interviewer can also ask for similarities and differences for situations put on the same 'line' group or on the same 'row' group.
- Repeat for the other situations (in order **b-h**) until all done.

- Interviewer may want to challenge the choices for matching the pupils make for the following situations:

For change **a** - *smoke filling the air* - she can ask whether it can be matched to pictures 2 (A) or 2 (C) [false alternative].

For change **e** - *wood burning* - she can ask whether it can be matched to pictures 3 (A) or 4 (A).

For change **g** - *getting salt by evaporating salt solution* - she can ask whether it can be matched to pictures 1 (A and C) or 4 (A and C).

For change **h** - *warming your hands by the radiator* - she can ask whether it can be matched to pictures 1(B) or 3 (B).

In each case it is better if interviewer says that these alternative 'matches' were suggested to her by other groups of children.

Task 3: Comparing situations

- Interviewer may also want to ask for similarities and differences for the following pairs of situations:

b-h a cold drink left out in the sun - warming your hands by the radiator

d-e melting wax - wood burning

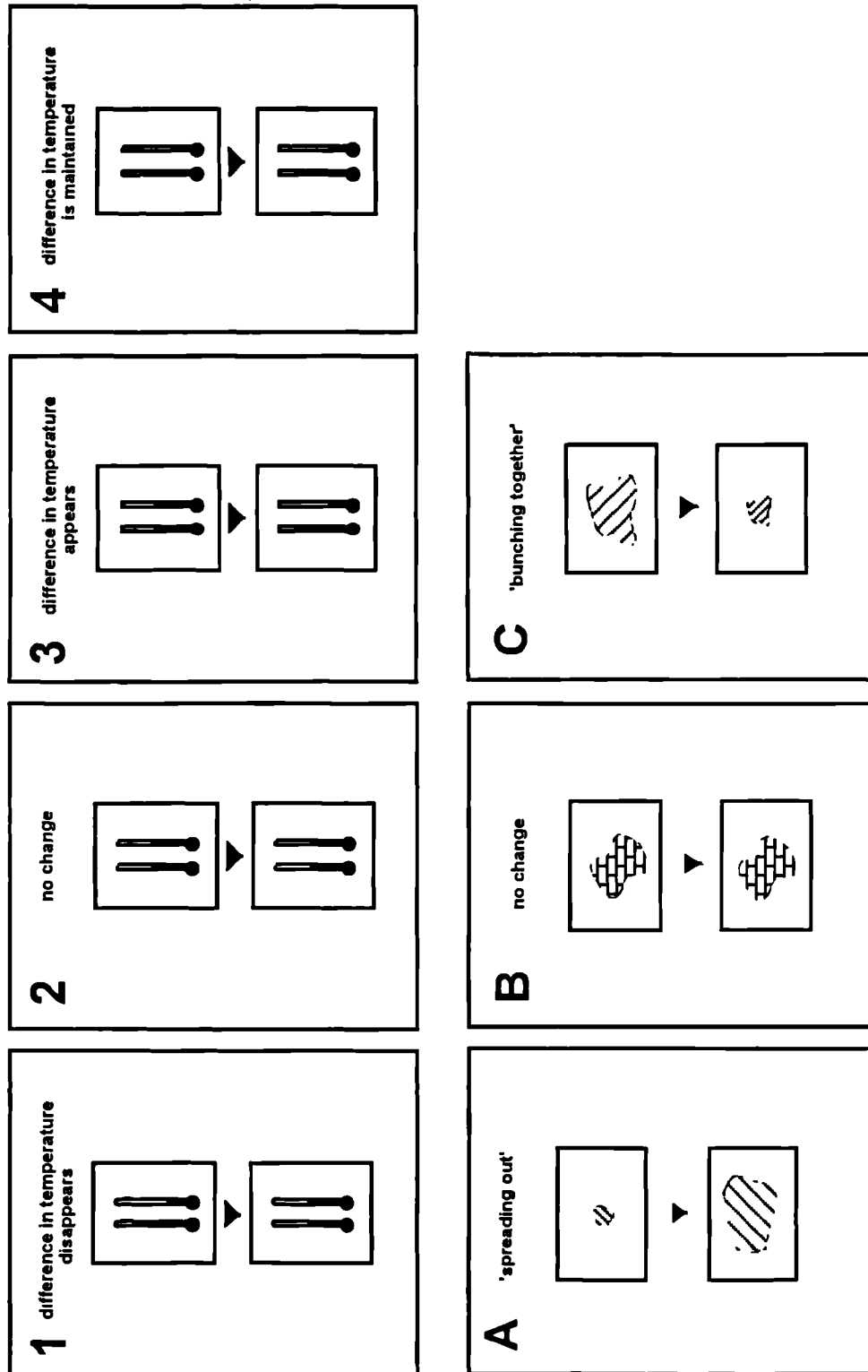
c-f water vapour forms clouds - your body staying warm on a cold day

- If there is time, after each pair of situations is examined / discussed for similarities and differences, the interviewer provides cards with sentences and asks pupils whether they think these are true for both or for one of the situations under examination. The sentences to discuss are:

it happens by itself

it makes a new substance

Abstract pictures for Y7 Third (C) Interview



Appendix 5.5

Interview schedule: SC Y7 Fourth

Write down pupils names in order from left to right.

Explain to pupils what will happen. They will look for similar changes.

Task 1: Linking similar changes

- Lay out 8 situations clockwise from **a** - at the top of the poster paper - to **h**. Interviewer reads through text on cards and tells pupils to think about what is changing in each one. She picks change **a** and then tells the children to look at all the others and find the one they think is most similar to it. They can link them with an arrow on the poster starting from the one the interviewer picks to the one they find as similar to it. Then the interviewer picks the next - going clockwise - change which doesn't have arrows ending at it and the pupils again look for the best similar change among all the others. The same procedure is repeated for the remaining changes. The task should last approximately 10 minutes. If there is left time the interviewer may ask children to think also about the situations she skipped in the first round.
- After each linking ask about reasons. Then explain that they will look at some examples in more detail in the second task.
- Write down letters of situations on poster paper before removing them.
- Situations chosen:
 - a** a plant growing (order - L1)
 - b** running and using up food (disorder - L6)
 - c** ice forming on a pond (freezing - PH4)
 - d** sweating to stay cool (disorder, 'keeping a balance' - L7)
 - e** wood burning ('spreading out' - CH2)
 - f** acid rain eroding a stone statue (dissolving - CH1)
 - g** your body making extra fat (order - L8)
 - h** a hot bath cools down (cooling - E1)

Task 2: Matching situations to representations

- On an other poster paper interviewer lays down 6 representations in two groups:

1. 'spreading out'	2. 'bunching together'	3. no change
4. disappearing	5. appearing from nothing	6. keeping a balance

and goes over with the pupils what each of the representations shows. They will need to match situations to these pictures.

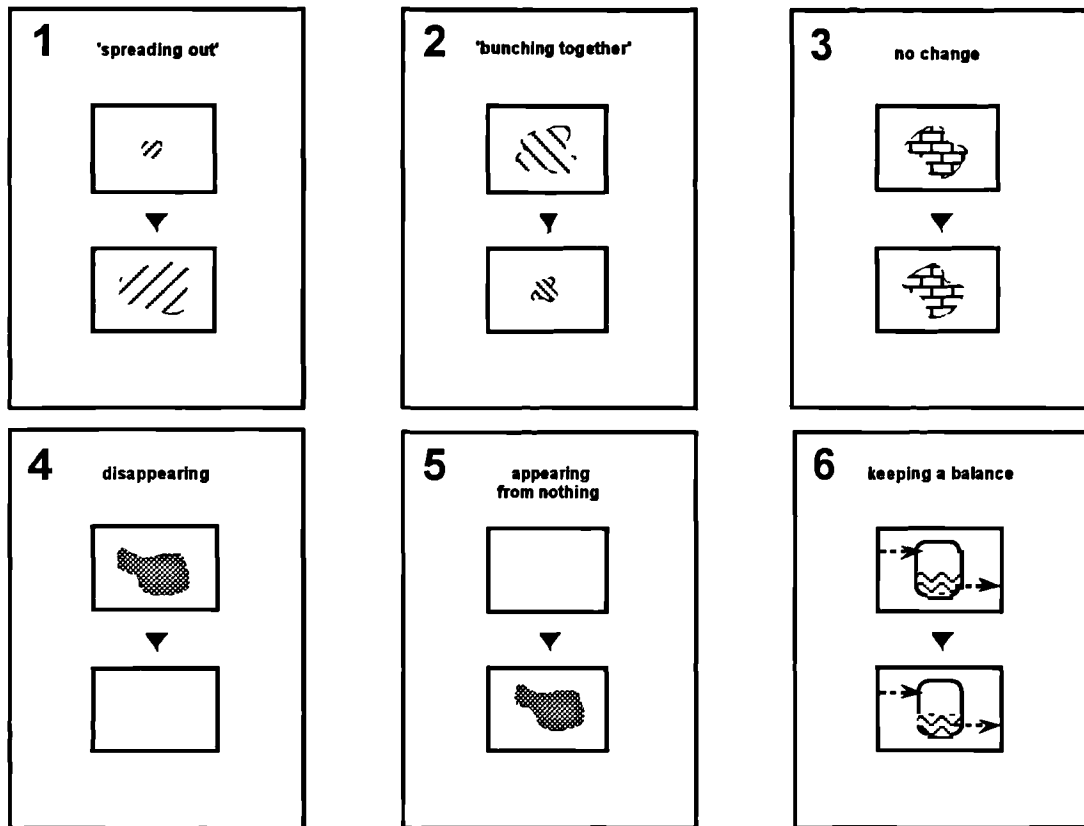
- Each pupil is given 6 cards with numbers 1-6 on them. Explain that these are to be used to show what they think other pupils will choose.
- Give first situation (**a**) to first pupil from left.

- Before putting this next to representation, others pupils should put chosen cards face-down.
- Other pupils show cards.
- Interviewer reads out numbers to record on tape - pupil matching situation first, then the other three in order from left to right.
- Ask pupil why the representation was chosen.
 - If no pupil disagrees, move on.
 - If one other pupil disagrees, ask that pupil for a reason.
 - If more than one disagrees, open it to all to give reasons.
 Does (first) pupil want to change mind or leave it where it is? (No reason needed.)
- If situation is matched to a representation which already has another situation, interviewer can ask:
 - You have matched these to the same picture. How are these situations similar?
 - Are there any differences between these situations?
- Repeat for the other situations (in order **b-h**) until all done.

Task 3: Comparing situations

- Interviewer may also want to ask for similarities and differences for the following pairs of situations:
 - g-a** your body making extra fat - a plant growing
 - b-e** running and using up food - wood burning
 - d-c** sweating to stay cool - ice forming on a pond
- If there is time, after each pair of situations is examined / discussed for similarities and differences, the interviewer provides cards with sentences and asks pupils whether they think these are true for both or for one of the situations under examination. The sentences to discuss are:
 - it makes a new substance*
 - something 'spreads out'*
 - it is easy to reverse the change*

Abstract pictures for Y7 Fourth (D) Interview



Appendix 5.6

Interview schedule: SC Y8 First

Write down pupils names in order from left to right.

Explain to pupils what will happen. They will look for similar changes.

Task 1: Linking similar changes

- Lay out 12 situations. Interviewer reads through text on cards and tells them to think about what is changing in each one. She asks them to pick one change and then to look at all the others and find the one they think is most similar. They can link them with a line on the poster and write their reason on the line. Then they look for another change (until they exhaust all situations) and repeat the same procedure.
- After each linking ask about reasons. Then explain that we will look at some examples in more detail.
- Write down letters of situations on poster paper before removing them.
- Situations chosen:
 - a scent or after-shave evaporating from the skin (evaporation - PH1)
 - b ice forming on a pond (freezing - PH4)
 - c a cold drink left out in the sun (warming - E3)
 - d acid rain eroding a stone statue (dissolving - CH1)
 - e hot lava from a volcano turns solid (freezing - PH5)
 - f making soup out of powder soup and water (dissolving - M3)
 - g fruit drying in the sun (evaporation - PH3)
 - h a plant growing (order - L1)
 - i a car windscreen being shattered (breaking - M2)
 - j wood burning (CH2)
 - k digesting food (disorder - L5)
 - l a hot bath cools down (cooling - E1)

Task 2: Looking at some changes in detail

- Interviewer has selected the following 4 pairs of situations:
 - hot bath cools down - a cold drink left out in the sun
 - ice forming on a pond - hot lava from a volcano turns solid
 - wood burning - plant growing
 - making soup out of powder soup and water - acid rain eroding a stone statue
- Interviewer lays down one of the above pairs. Then she gives each pupil five sentences written on separate cards (randomly out of a total of twenty sentences). While she does that, she reads the sentences out as well. Then she asks each pupil in turn from left to right to pick one sentence -out of the five- that is true for both changes (similarity), or if he she does not find one, a sentence that is true for one of the changes, and put it in the middle of the poster. If there is time the interviewer asks for a second best. After all the pupils have made at least one choice the interviewer goes over the sentences chosen and asks the group to agree for each one of them in turn as to whether it is true for both or for one of the changes, and to place it accordingly on the poster -i.e. either between or under the situations. Interviewer prompts them to talk about the reasons behind their choice.

- Then the interviewer presents another set of (maximum) six sentences -selected for each pair of situations for being interesting to discuss- and asks again pupils to say whether they think these are true for both or for one of the changes. If in this set there are sentences already discussed, these are taken out of the set.
- Repeat for other 3 pairs of situations.

Key sentences for Y7 and Y8 First (A) Interviews

something 'spreads out'

something 'bunches' together

something is mixing

something is unmixing

something gets warmer

something gets cooler

temperature evens out

something becomes solid

something becomes liquid

something becomes gas

it makes a new substance

substances stay the same

it happens by itself

someone makes it happen

something disappears
or gets used up

energy 'spreads out'

temperature stays the same

a substance changes

it is easy to reverse the change

energy becomes concentrated
in something

Appendix 5.7

Interview schedule: SC Y8 Second

Write down pupils names in order from left to right.

Explain to pupils what will happen. They will look for similar changes.

Task 1: Linking similar changes

- Lay out 8 situations clockwise from **a** -at the top of the poster paper- to **h**. Interviewer reads through text on cards and tells pupils to think about what is changing in each one. She picks change **a** and then tells the children to look at all the others and find the one they think is most similar to it. They can link them with an arrow on the poster starting from the one the interviewer picks to the one they find as similar to it. Then the interviewer picks the next - going clockwise - change which doesn't have arrows ending at it and the pupils again look for the best similar change among all the others. The same procedure is repeated for the remaining changes. The task should last approximately 10 minutes. If there is left time the interviewer may ask children to think also about the situations she skipped in the first round.
- After each linking ask about reasons. Then explain that they will look at some examples in more detail in the second task.
- Write down letters of situations on poster paper before removing them.
- Situations chosen:
 - a** a snowman melting (change of state - PH9)
 - b** a car rusting ('joining' - CH4)
 - c** extracting copper by electrolysis copper sulphate solution ('splitting' - CH6)
 - d** cleaning a paint brush in water ('mixing' - M4)
 - e** a baby's bones growing ('re-arranging' - L3)
 - f** purifying water ('unmixing' - M5)
 - g** putting Alka Seltzer in water ('re-arranging' - CH5)
 - h** metal foil being crumpled up (shape of object changing - M1)

Task 2: Matching situations to representations

- On an other poster paper interviewer lays down 6 representations in two groups:

1. Joining	2. Splitting	3. Re-arranging
4. Mixing	5. Un-mixing	6. No change

and goes over with the pupils what each of the representations shows. They will need to match situations to these pictures.

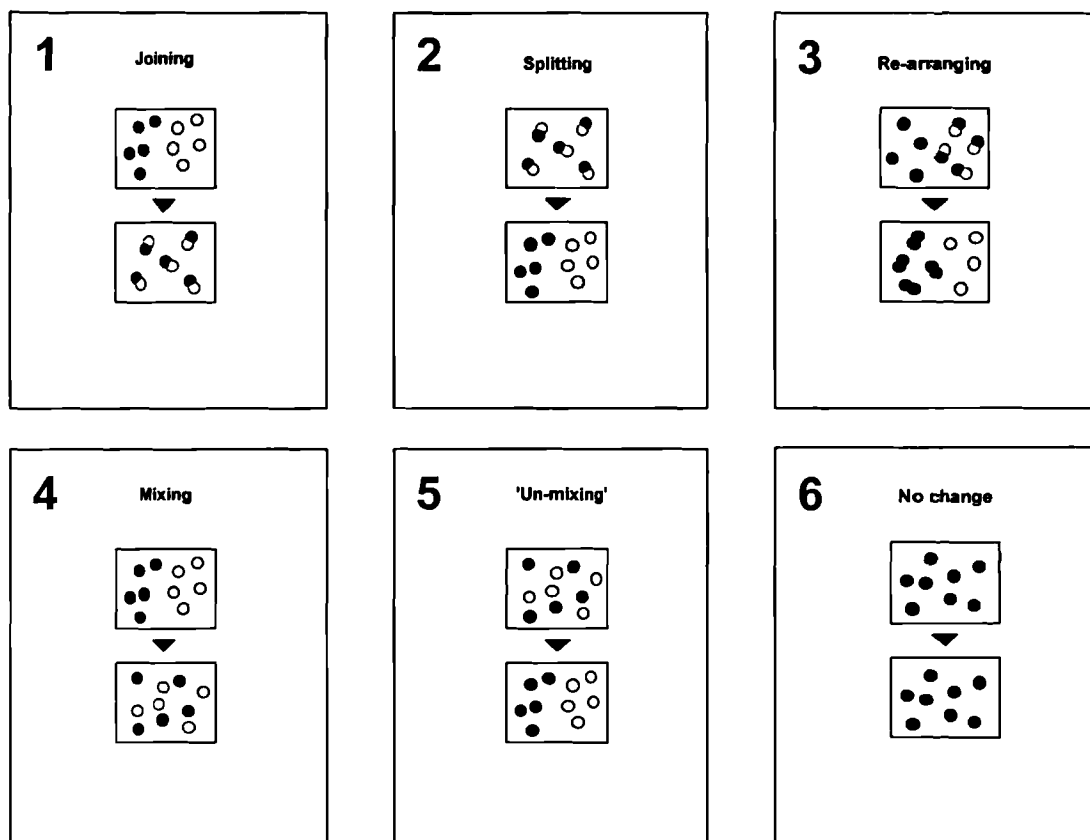
- Each pupil is given 6 cards with numbers 1-6 on them. Explain that these are to be used to show what they think other pupils will choose.
- Give first situation (**a**) to first pupil from left.

- Before putting this next to representation, others pupils should put chosen cards face-down.
- Other pupils show cards.
- Interviewer reads out numbers to record on tape - pupil matching situation first, then the other three in order from left to right.
- Ask pupil why the representation was chosen.
 - If no pupil disagrees, move on.
 - If one other pupil disagrees, ask that pupil for a reason.
 - If more than one disagrees, open it to all to give reasons.
 Does (first) pupil want to change mind or leave it where it is? (No reason needed.)
- If situation is matched to a representation which already has another situation, interviewer can ask:
 - You have matched these to the same picture. How are these situations similar?
 - Are there any differences between these situations?
- Interviewer can also ask for similarities and differences for situations put on the same 'line' group or on the same 'row' group.
- Repeat for the other situations (in order **b-h**) until all done.

Task 3: Comparing situations

- Interviewer may also want to ask for similarities and differences for the following pairs of situations:
 - c-f** extracting copper by electrolysis CuSO_4 solution - purifying water
 - g-d** putting Alka Seltzer in water - cleaning a paint brush in water
 - b-e** a car rusting - a baby's bones growing
- If there is time, after each pair of situations is examined / discussed for similarities and differences, the interviewer provides cards with sentences and asks pupils whether they think these are true for both or for one of the situations under examination. The sentences to discuss are:
 - it is easy to reverse the change*
 - it happens by itself*

Abstract pictures for Y8 Second (B) Interview



Appendix 5.8

Interview schedule: SC Y8 Third

Write down pupils names in order from left to right.

Explain to pupils what will happen. They will look for similar changes.

Task 1: Linking similar changes

- Lay out 8 situations clockwise from **a** -at the top of the poster paper- to **h**. Interviewer reads through text on cards and tells pupils to think about what is changing in each one. She picks change **a** and then tells the children to look at all the others and find the one they think is most similar to it. They can link them with an arrow on the poster starting from the one the interviewer picks to the one they find as similar to it. Then the interviewer picks the next - going clockwise - change which doesn't have arrows ending at it and the pupils again look for the best similar change among all the others. The same procedure is repeated for the remaining changes. The task should last approximately 10 minutes. If there is left time the interviewer may ask children to think also about the situations she skipped in the first round.
- After each linking ask about reasons. Then explain that they will look at some examples in more detail in the second task.
- Write down letters of situations on poster paper before removing them.
- Situations chosen:
 - a** an electric iron cools down after being switched off (energy 'spreads out' - E2)
 - b** water vapour forms clouds and it rains (matter 'bunches together', change of state - PH8)
 - c** melting wax (matter 'spreads out', change of state - PH10)
 - d** smoke filling the air over a city (matter 'spreads out' - M6)
 - e** your body making extra fat (matter 'bunches together' - L4)
 - f** warming your hands by the radiator (energy becomes concentrated - E4)
 - g** an explosion (matter 'spreads out', energy 'spreads out' - CH3)
 - h** your body staying warm on a cold day (steady state - L8)

Task 2: Matching situations to representations

- On an other poster paper interviewer lays down 7 representations in a matrix format (1-4 horizontally and A-C vertically):

	1. energy spreads out	2. no energy change	3. energy becomes concentrated	4. energy stays concentrated
A. 'spreading out'				
B. no change				
C. 'bunching together'				

and goes over with the pupils what each of the representations shows. They will need to match situations to these pictures.

- Each pupil is given 7 cards with numbers 1-4 and letters A-C on them. Explain that these are to be used to show what they think other pupils will choose.
- Give first situation (a) to first pupil from left.
- Before putting this next to representation, others pupils should put chosen cards face-down.
- Other pupils show cards.
- Interviewer reads out numbers to record on tape - pupil matching situation first, then the other three in order from left to right.
- Ask pupil why the representation was chosen.
If no pupil disagrees, move on.
If one other pupil disagrees, ask that pupil for a reason.
If more than one disagrees, open it to all to give reasons.

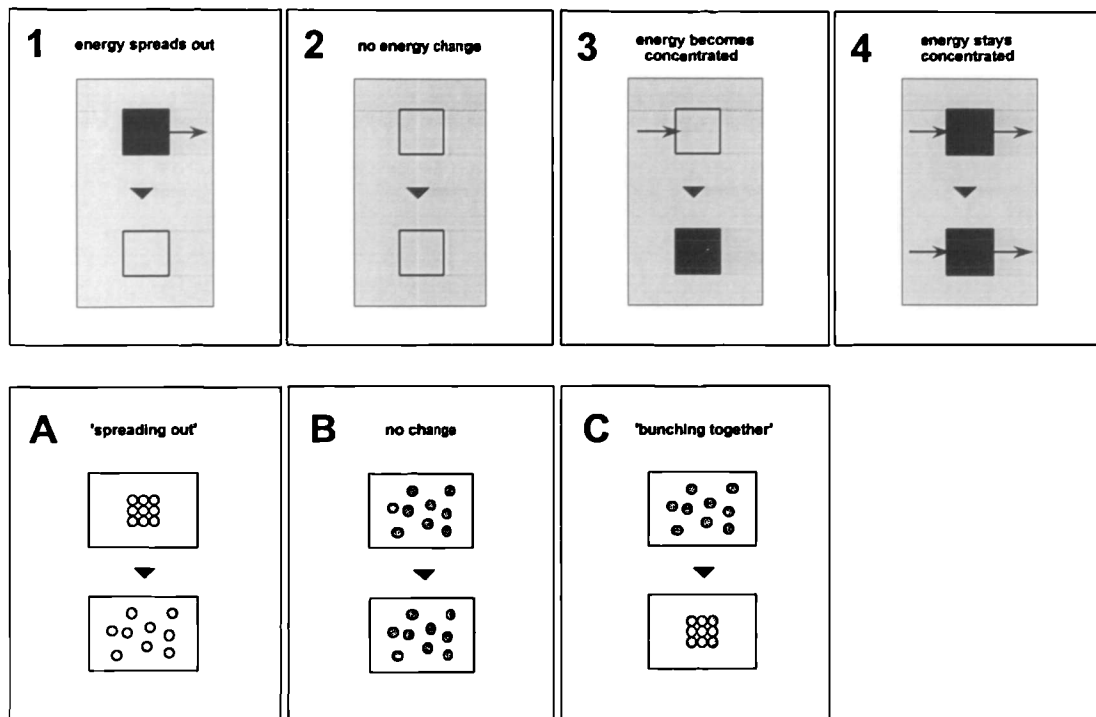
Does (first) pupil want to change mind or leave it where it is? (No reason needed.)

- If situation is matched to a representation which already has another situation, interviewer can ask:
You have matched these to the same picture. How are these situations similar?
Are there any differences between these situations?
- Interviewer can also ask for similarities and differences for situations put on the same 'line' group or on the same 'row' group.
- Repeat for the other situations (in order **b-h**) until all done.
- Interviewer may want to challenge the choices for matching the pupils make for the following situations:
For change **c** - *melting wax* - she can ask whether it can be matched to pictures **3 (A)** or **4 (A)** or **1 (A)**.
For change **e** - *your body making extra fat* - she can ask whether it can be matched to pictures **1 (C)** or **4 (C)**.
For change **f** - *warming your hands by the radiator* - she can ask whether it can be matched to pictures **1(B)** or **3 (B)**.
In each case it is better if interviewer says that these alternative 'matches' were suggested to her by other groups of children.

Task 3: Comparing situations

- Interviewer may also want to ask for similarities and differences for the following pairs of situations:
 - a-f** an electric iron cools down after being switched off - warming your hands by the radiator
 - g-d** an explosion - smoke filling the air over a city
 - b-e** water vapour forms clouds - your body making extra fat
- If there is time, after each pair of situations is examined / discussed for similarities and differences, the interviewer provides cards with sentences and asks pupils whether they think these are true for both or for one of the situations under examination. The sentences to discuss are:
 - it is easy to reverse the change*
 - it makes a new substance*

Abstract pictures for Y8 Third (C) Interview



Appendix 5.9

Interview schedule: SC Y8 Fourth

Write down pupils names in order from left to right.

Explain to pupils what will happen. They will look for similar changes.

Task 1: Linking similar changes

- Lay out 8 situations clockwise from **a** -at the top of the poster paper- to **h**. Interviewer reads through text on cards and tells pupils to think about what is changing in each one. She picks change **a** and then tells the children to look at all the others and find the one they think is most similar to it. They can link them with an arrow on the poster starting from the one the interviewer picks to the one they find as similar to it. Then the interviewer picks the next - going clockwise - change which doesn't have arrows ending at it and the pupils again look for the best similar change among all the others. The same procedure is repeated for the remaining changes. The task should last approximately 10 minutes. If there is left time the interviewer may ask children to think also about the situations she skipped in the first round.
- After each linking ask about reasons. Then explain that they will look at some examples in more detail in the second task.
- Write down letters of situations on poster paper before removing them.
- Situations chosen:
 - a** a plant growing (energy is stored, easier backwards - L1)
 - b** running and using up food (energy escapes, easier forwards - L6)
 - c** ice forming on a pond (energy escapes, easier forwards - PH4)
 - d** charging a car battery (energy is stored, easier backwards - CH7)
 - e** wood burning (energy escapes, easier forwards - CH2)
 - f** acid rain eroding a stone statue (dissolving - CH1)
 - g** pulling a catapult to get ready to fire a stone (energy is stored, easier backwards - E5)
 - h** a hot bath cools down (energy escapes, easier forwards - E1)

Task 2: Matching situations to representations

- On an other poster paper interviewer lays down 7 representations in a matrix format (1-5 horizontally and A-B vertically):

	1. energy escapes I	2. energy escapes II	3. no energy change	4. energy is stored I	5. energy is stored II
A. it 'just happens' by itself					
B. it needs something to make it happen					

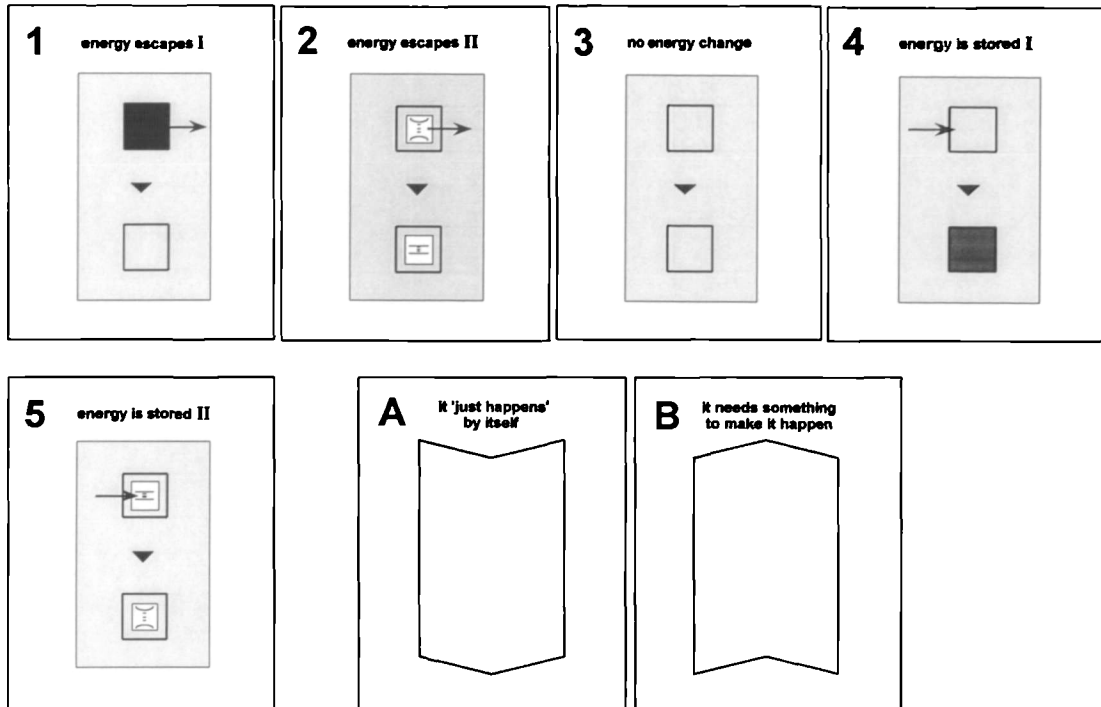
and goes over with the pupils what each of the representations shows. They will need to match situations to these pictures.

- Each pupil is given 7 cards with numbers 1-5 and letters A-B on them. Explain that these are to be used to show what they think other pupils will choose.
- Give first situation (a) to first pupil from left.
- Before putting this next to representation, others pupils should put chosen cards face-down.
- Other pupils show cards.
- Interviewer reads out numbers to record on tape - pupil matching situation first, then the other three in order from left to right.
- Ask pupil why the representation was chosen.
 - If no pupil disagrees, move on.
 - If one other pupil disagrees, ask that pupil for a reason.
 - If more than one disagrees, open it to all to give reasons.
 Does (first) pupil want to change mind or leave it where it is? (No reason needed.)
- If situation is matched to a representation which already has another situation, interviewer can ask:
 - You have matched these to the same picture. How are these situations similar?
 - Are there any differences between these situations?
- Interviewer can also ask for similarities and differences for situations put on the same 'line' group or on the same 'row' group.
- Repeat for the other situations (in order **b-h**) until all done.

Task 3: Comparing situations

- Interviewer may also want to ask for similarities and differences for the following pairs of situations:
 - d-g** charging a car battery - pulling a catapult to get ready to fire a stone
 - b-e** running and using up food - wood burning
 - b-h** running and using up food - a hot bath cools down
- If there is time, after each pair of situations is examined / discussed for similarities and differences, the interviewer provides cards with sentences and asks pupils whether they think these are true for both or for one of the situations under examination. The sentences to discuss are:
 - something 'spreads out'*
 - it is easy to reverse the change*

Abstract pictures for Y8 Fourth (D) Interview



Appendix 5.10

Rationale for Y7 Second (B) Interview

Task 1: Linking similar changes

The first task - the 'grouping' task or the 'Wheel' - is important because it is a simple task in which children have the chance to be spontaneous. In this way we can see what they are really thinking about the changes.

All changes are laid down forming a circle. Starting from the top and going clockwise I put the situations in order, so that the first ones are the ones the pupils are more familiar with. At first I ask them to focus their attention on the one placed on the top and then to look at all the others and choose the one they find most similar to that top one. They talk it over to reach a consensus. Once they tell me the reason(s) for their choice I draw an arrow between the two situations, starting from the one I picked to the one they chose as similar. So, the one I pick each time plays the role of the trigger. That is one of the reasons why I decided to put the ones they are more familiar with - they have received some teaching about them - at the start of the 'wheel'. Another reason comes from the fact that due to time constraints this task should not last more than 10 minutes if the whole interview is to last 30-35 minutes. The situations I laid at the beginning of the 'wheel' are the ones we want them to talk about, because they are the ones they have had some teaching about and therefore they are the ones about which we might expect that some change in their thinking might have occurred.

After having worked with the first situation I move on to the second one -going clockwise- and stop at it unless there is already an arrow leading to it. If this is so I move on to the one after and repeat the same procedure, until all the situations are exhausted or the 10 minutes are over. If there is time I go over the ones I have not done. The aim is to cover as many as possible in the given time.

The number of the situations chosen is eight. We were driven to this number first because of the need for the interview not to last more than 30 minutes -a need that was not met every time the interview took place-, and second because the groups to be interviewed consist of four pupils: having eight situations would give each pupil two opportunities to match a situation to a representation in the second task. The situations chosen are:

- a *crystals forming in copper sulphate solution as it cools:*
 - taught under the Water topic, pupils have done relevant investigation 'unmixing', crystallising, matter 'bunching together', energy spreading out
- b *cleaning a paint brush in water :*
 - taught under the Water topic
 - dissolving, matter spreading out
- c *the windows of the car misting up on a very cold day:*
 - met under the Water topic but will be seen in more detail under Air topic
 - condensation, matter 'bunching together', energy 'spreading out'
- d *purifying water:*
 - taught under the Water topic, pupils have done relevant investigation 'unmixing', matter 'bunching together'
- e *your hair growing:*
 - not met in lessons
 - order - life, matter 'bunching together'

- f** *warming your hands near the fire:*
-not met in lessons
warming, energy becomes more concentrated
- g** *an explosion:*
-not met in lessons
chemical reaction
- h** *an electric iron cools down after being switched off*
-not met in lessons
cooling, energy 'spreading out'

The criteria for the choice of the situations are:

- to have two situations where there is a 'matter' change only (**b** and **d**), two situations where there is an energy change only (**f** and **h**), to have two situations where there is a 'matter change' combined with an energy change (**a** and **c**), to have one situation showing a chemical reaction (**g**) and one showing a biological change.
- **a**, **b** and **d** are situations the pupils have met in the topic, although for change **a** no emphasis was given to the 'spreading out' of energy, so I expect a difference in their performance.
- **c** and **e** are situations about which they will learn in the coming topics, so I expect a difference in their performance to occur in the future.

Task 2: Matching situations to representations

In this task – 'matching' task - we are interested in how pupils abstract, make generalisations. We want to find out whether children take a certain kind of thinking on board.

In this task the pupils are working with the same situations they met in the first task but this time they match them to some abstract pictorial representations. My first thought was to use the representations used in the project for teaching dissolving, mixing, separating etc., but I found that they were very specific -each situation would match only to one picture-, thus they would neither promote discussion, nor would they be suitable for detecting similarities and/or differences among the changes. So talking with Dick we decided that the representations to be used in the interview should be rather abstract and vague. The first five representations we decided to have were:

- | | | |
|--------------------------|------------------------------|--------------------|
| 1 mixing | 2 'unmixing', | |
| 3 'spreading out' | 4 'bunching together' | 5 no change |

After discussing it with Jon we decided to also have two representations depicting something disappearing and something appearing from nothing. So:

- | | |
|-----------------------|---------------------------------|
| 6 disappearing | 7 appearing from nothing |
|-----------------------|---------------------------------|

The representations were stuck on a poster paper arranged as above. The setting was such that it could evoke similarities and differences between situations matched to representations in the same row or column. I also chose to have the same kind of shadings in the representations which show two opposite but similar kind of changes e.g. *mixing* and *'unmixing'*

'spreading out' and *'bunching together'*
disappearing and *appearing from nothing*

It is very important to explain to the pupils that some of the pictures may have no matches at all. What we are interested in is seeing how things may be the same or may differ.

Task 3: Comparing situations

After the children match the situations to the representations, where they have two or more changes matched to the same representation I should ask them for similarities and differences between these situations, to see if helped by the abstract picture they can reason more abstractly about the situations detecting also similarities that they did not see in the first task. If there is time I would also ask them about whether for the pair of situations under discussion the sentences 'someone makes it happen', 'it happens by itself', 'it is easy to reverse the change' are true for both or for one of the situations. Out of the twenty sentences used in the first interview we found that the ones that were not covered -in the sense of working as a trigger for children to talk about these ideas- by the representations were the above three and also the following five: 'energy becomes concentrated in something', 'energy 'spreads out'', 'something gets cooler', 'something gets warmer' and 'temperature evens out'. Of course if there is enough time I use the ones about energy as well. The rationale behind choosing to give priority to the first three is that we are interested to see whether pupils change in the way they see a process as natural or reversible. On the other hand because they have not had any teaching about energy we do not expect their thinking to change in that aspect during the year. Nevertheless, this was in a way an arbitrary choice guided by the desire to get the most out of it. The last three sentences about temperature were ruled out first because of time constraints, but also because the situations that they would apply (**a**, **c**, **f**, **h**) explicitly suggest the temperature or temperature change in their wording.

Apart from the pairs that will arise from their matching I chose three more pairs of situations that I would like them to talk about.

1. *your hair growing - the windows of the car misting up on a very cold day*
-something is 'bunching together' in both changes
2. *cleaning a paint brush in water - an explosion*
-matter is 'spreading out'
-'mixing' -in one situation dissolving
-in the other chemical reaction --> a new substance
3. *crystals forming in copper sulphate solution as it cools - purifying water*
-matter is 'unmixing'
-'bunching together'

1 situations are counter intuitive but in the same way, i.e. they both look like 'spreading out' but are 'bunching together'.

2 and 3 are situations selected because they are 'similar'. I expect that the pupils will have come up already with pairs of situations 'different' in kind, so they will have talked about them anyway. Also most of them are situations they have met in the Water topic and thus are changes I should expect them to have learned something about.

Appendix 5.11

Classroom Observation in Year 7

Y7-WATER 05

Thursday 2/12 93

Teacher: Anna

Topic: **Water**

Duration: 1 hour

Project's activity: **Backwards and forwards in the kitchen (A1).**

The lesson started with the pupils spelling the word 'condensation'. Then Anna told them that they would start thinking about dissolving, and asked them what they thought dissolving was. Among the different suggestions children gave were: *if you put something in water it breaks; it's a solid first and when you put it in water and mix it, it becomes a liquid* - concerning the last suggestion I am not sure whether it was a pupil who uttered it and not Anna. When Anna brought up the example of a sugar cube a child said: 'It will mix up and you don't see it anymore'. Then Anna, went on asking what a solution was. After getting some responses, she asked whether they thought it was easier to dissolve a sugar cube and get sugar water, or get a sugar cube out of sugar water. A child answered 'It's easier making it' meaning that it is easier to make sugar water.

Then Anna told them to put the heading *Backwards and forwards in the kitchen* in their books and showed them the relevant OHP - A1/1 Sheet 1 produced by Richard Boohan. She first read the first sentence - *Some changes happen more easily than others* - and asked: 'Is it easier to boil an egg or to unboil?' All the pupils answered 'to boil' but when she further asked whether you could get the egg back there were two pupils who answered *yes*. Anna corrected them saying: 'You can't get it back. ... It's a chemical reaction.' Next question was whether ice was solid, liquid, or gas, the children answered correctly - *solid* -, and then there was a mention to melting and freezing that I wasn't able to record.

Continuing with what was written on the OHP, Anna asked whether you could get a mug out of a broken mug and at least a couple of children offered the possibility of using a super glue to put it back. She accepted the answer but she also drew their attention to the fact that the mug was not going to be the same as it had been before. Considering however the possibility of getting back the onion from chopped onion she refuted it in an absolute way: 'The onion you can't get it back'. But, there was again one pupil who in a low voice tried to give an alternative: 'unless you get...!'

She then distributed Sheet 2 - A1/2 - and told them to cut out the pictures, stick them in their books and write whether it was easier to go Forwards or Backwards. 'Forwards is down and Backwards is up'. She also told them that some of them were impossible. At that moment I thought that she was not giving them the 'correct' instructions or any way, the instructions that were on the sheet and I wondered whether that was on purpose. That created a small confusion as some of the pupils read the instructions and got confused about what to do. When she realised what had happened she changed the instructions, giving now the 'correct' ones.

Each child was working on his/her own as it was an individual exercise and I was moving from table to table to see how they were doing and what problems they had. The six pupils I am closely following were all present but not seated in pairs. This did not affect my observation in this case, as they were working individually.

Sadiq got them all right. When I asked Teresa why it was *Easier Forwards* in the D picture - *washing-up liquid and water* going to *soapy water* - she said: 'You need washing-up liquid and water to make soapy water, but you don't need soapy water to make washing-up liquid and water.' For picture E - *soap powder and water* going to *soapy water* - however, and to the same question Dionne answered: 'Soap powder and water make soapy water, but soapy water doesn't make soap powder and water.' I found quite interesting the fact that Teresa was stressing the structure *you need* vs. *you don't need* while Dionne preferred *it makes* vs. *it doesn't make*. In order to see whether Dionne would use consistently the same structure to explain me another picture I asked him about the change in the picture I - *coffee powder and hot water* going to *hot coffee* -. This time he said 'Once you have mixed it, you can't take the coffee powder out'. Listening to him Sadiq dropped the word 'refine' in a brief sentence I did not get. His intention was to show that there is a way to get back things like coffee powder from hot coffee.

THOUGHTS - IMPRESSIONS

(1) Generally speaking, I found that the pupils could on the whole do the activity. What they could not understand at the beginning were the notions of 'Forwards' and 'Backwards' in combination with the sequence of the pictures. A girl asked me whether the small arrow linking the two pictures meant 'Forwards' or 'Backwards'; Dionne kept thinking forwards as upwards and backwards as downwards etc. When I was going around, in my responses to their questions I tended to use the words 'downwards' and 'upwards' which I felt helped me explain and most times helped them understand. Also, I noticed that they found helpful to draw an arrow next to the pictures depicting the easier order of the changes.

(2) In telling me their reasons they hardly used the terms 'mixing' and 'unmixing' but I felt that that was because Anna had not mentioned these terms, certainly not encouraged them to use them. I, talking to pupils used these terms many times to show them how they should think about the changes. Nevertheless, only very few times they used them themselves in reasoning, even after I had done so. I wonder whether they will appear in their writings. Looking briefly in their books, however I noticed that Anna had crossed the word 'unmixing' used by a pupil, and had written 'separated'. A reason for that may have been that earlier that morning Richard Boohan had told her that he was going to prepare some activities on separating, and on comparing separating with mixing.

(3) It would be very interesting to see what reasons they gave in their books.

(4) Picture C created more problems than the others, many thought of it as *Easier Forwards* - i.e. *gravy* going to *gravy granules and hot water*. After the lesson Anna told me that most children did not understand what gravy was. This could perhaps explain my observation.

(5) After the lesson Anna told me that she found that once children understood what they were meant to do - the ideas of 'Backwards' and 'Forwards' - they did it very well. They were certainly involved with it for a long time, without complaining.

(6) It is however true that they shared the knowledge of which pictures are *Easier Forwards* among themselves, and also that both Anna and me helped them to pick the correct ones before they stuck them in their books. So, I don't have any data about how many pupils they could do the task without help. Perhaps the most interesting data will be the reason they gave for classifying these changes as *Easier Forwards*, although I fear that most of their reasons will be in the form of description of the change and not really saying why they think the changes go forwards more easily than backwards.

Appendix 5.12

Project's activity and teaching notes for 'Backwards and forwards in the kitchen'

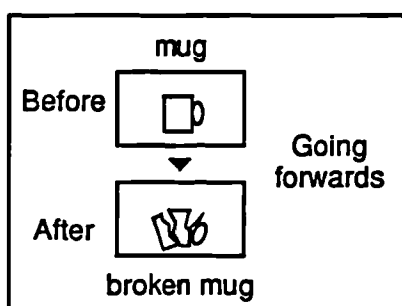
Backwards and forwards in the kitchen

Sheet 1

Some changes happen more easily than others.

Breaking a mug

These pictures show a mug breaking.



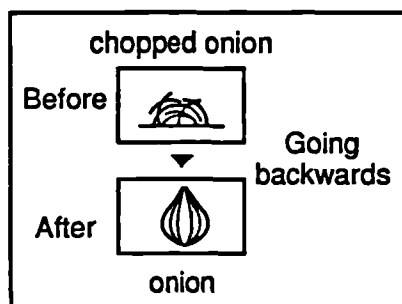
If you saw a video of this happening, you would guess that it was being played *forwards* not *backwards*.

It is easier to break a mug than to get the mug back.

This change happens more easily forwards than backwards.

'Unchopping' an onion

These pictures show an onion being 'unchopped' to make a whole onion.



If you saw a video of this happening, you would guess that it was being played *backwards* not *forwards*.

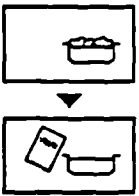
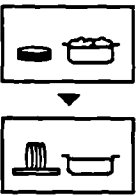
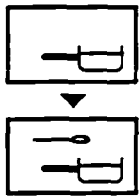
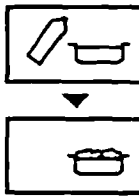
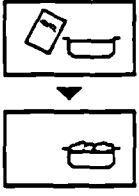
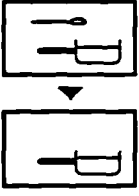
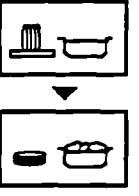
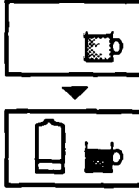
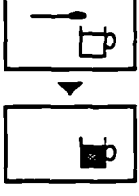
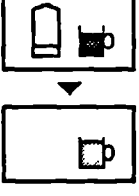
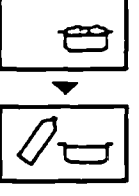
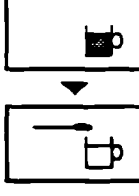
It is easier to chop up an onion than to get the onion back.

This change happens more easily backwards than forwards.

Backwards and forwards in the kitchen

Sheet 2

- 1 Cut out the pictures below.
- 2 Sort them into two groups 'Going forwards' and 'Going backwards'.
- 3 Stick the pictures in the group 'Going forwards' in your books.
- 4 Why do you think these changes go forwards more easily than backwards?

A soapy water  soap powder and water	B dirty plates and clean water  clean plates and dirty water	C salty water  salt and water	D washing-up liquid and water  soapy water
E soap powder and water  soapy water	F salt and water  salty water	G clean plates and dirty water  dirty plates and clean water	H white coffee  milk and black coffee
I coffee powder and hot water  hot coffee	J milk and black coffee  white coffee	K soapy water  washing-up liquid and water	L hot coffee  coffee powder and hot water

Activity A1 - Backwards and forwards in the kitchen

The activity is about dissolving. Changes in which things are mixed (e.g. dissolving) happen more easily than changes in which they are 'unmixed'.

Sheet 1 contains information about the task, and may be used as an OHP. The idea of changes which happen more easily in one direction is introduced by thinking about a video of such changes being shown 'forwards' or 'backwards'.

Sheet 2 is for pupils. Each change on this sheet appears twice - once forwards and once backwards. The reason for this is to encourage pupils to think about each change in both directions and to familiarise them with the 'before' and 'after' conventions used in these materials.

Answers:

'Going forwards' - B, D, E, F, I, J

'Going backwards' - A, C, G, H, K, L

In writing up their reasons, pupils should be encouraged to use the terms 'mixing' and 'unmixing'.

Activity A2 - Pictures of mixing

The activity is about matching changes to abstract pictures involving mixing. It also encourages pupils to think about mixing as a process in which substances 'spread out'.

Sheet 1 introduces the conventions of the abstract pictures with matched examples, and may be used as an OHP. The conventions are:



When discussing these pictures with the class, pupils should be encouraged to use the list of words shown. For example:

- Coffee powder is a *solid*, hot water is a *liquid*. The coffee is *soluble* in water. They *mix* to make a *liquid*. The coffee *dissolves* in the water. The coffee *spreads out* into the water.
- Milk and black coffee are both *liquids*. When they are *mixed*, the milk *spreads out* into the coffee.

Appendix 5.13

Examples of pupils' written work for 'Backwards and forwards in the kitchen'

Backwards and forwards in the kitchen

1



It is easier forwards because you use milk and black to make coffee. When you mix something like that you can not separate them.

2



It is easier forwards because you need clean water to clean dirty plates. When you do this you can not put the dirt from the water back on to the plate.

3



It is easier forwards because you need coffee powder and hot water to make hot coffee. When you make coffee you can not separate the coffee powder and the hot water.

4



It is easier forwards because you use gravy granules and hot water to make gravy. You can not separate the gravy granules and the hot water.

5



It is easier forwards because you use soap powder and water to make soapy water. You can not take out the soap powder from the water.

6



It is easier forwards because you need washing up liquid and water to make soapy water. You can not take the washing up liquid out of the water.

Do solids sink or float?
Solids sink most solids sink

What does ice do, why is it important?
Ice floats it is important because it protects the animals in the water.

Dissolving

6/12/93

Dissolving is when a solvent and a solute mix together to make a solution.

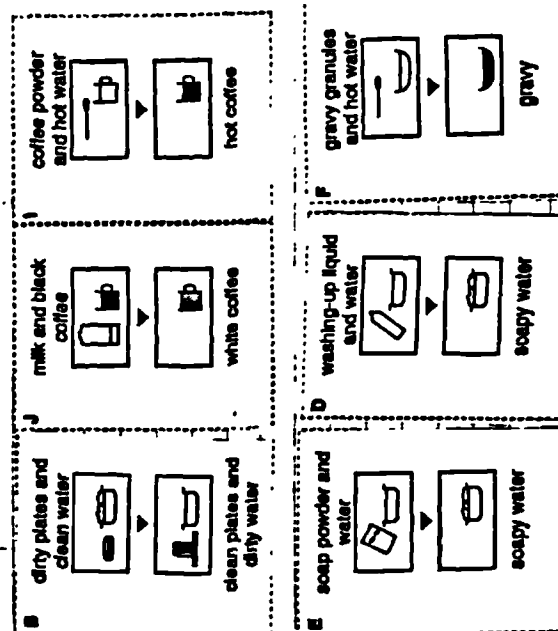
A solvent is a liquid. A solute is usually a solid. The particles of a solute bump into the particles of a solvent and break them off. They mix up and spread out.

work

1. Do Solish sink or float?
2. What does ice do? Why is it important that it does this?

Background forwards in the kitchen
Thursday 2nd December 1992

Easier forwards



- B= It's easier to have clean plates and dirty water than dirty plates and clean water.
- J= It's easier forwards because it's easier to have white coffee from milk and black coffee.
- I= It's easier because coffee powder and hot water make black coffee.
- D= It's easier to make soapy water from washing-up liquid and water.
- ED= It's easier to make soapy water from soap powder and water.
- F= It's easier to make gravy from granules and hot water.
- There's easier because say if you had soapy water which was made from soap powder once the powder has been mixed in you can't take it out again. It's easier to mix something than to unmix it.

Appendix 5.14

Interviews with Teachers

1.

Here are some of the criticisms we have heard about the project. I would like to discuss with you each one of them.

Difficulties in using the project's material or in thinking about how to use it:

- Pictures are very abstract and have too many conventions. Pupils won't be able to make sense of them, even less use them.
- A special vocabulary to be learned which is not even scientific and is different from textbooks.
- I don't see how I can find good places for the activities in the existing schemes of work.
- I don't really see the point of all the work comparing pictures and talking about them. Some practical experiences would be better.
- The ideas behind it are too general; what pupils need is a lot of interesting particular things to think about.
- It's certainly a different approach to teaching certain things, but I don't see what new ideas it introduces.

2.

Now, some of the things the teachers have suggested that the project's material may be helpful for. I would like to have your opinion on each one of them

Ways in which this material can be helpful:

- It helps keep the children active and busy, discussing and thinking.
- It introduces the particle nature of matter in a way accessible to Year 8 and Year 9 pupils.
- The activities are accessible to low ability pupils, and can help ones with language difficulties.
- The activities offer a challenge to higher ability pupils, to think hard.
- It can be used easily alongside existing schemes.
- It is easy to see how some of the activities could follow practical work, building on it.
- It helps teachers to find simple ways of talking with pupils about energy and physical and chemical changes.

- The ideas are fundamental, and can help link together many parts of science, up to GCSE and beyond.
- It gets teachers thinking again about ideas they may not have felt very sure about, and helps them sort these ideas out a bit better.

3.

What do you see as the main things the project is trying to achieve?

4.

*Show the teachers again INSET activities (**'Putting changes into groups'** (Activity C5); **'Joining and splitting some examples'** (Activity G6); **'The weather -warmth, wind and waves'** (later renamed **'Wind, waves and water'** - Activity J6) and ask:*

How do you see these achieving something in the long run helping to build up children's ideas / as children's ideas build up?

Appendix 5.15

Energy and change - evaluation questionnaire

Here are some of the kinds of comments we have had about the approach. Do you agree or disagree?

	strongly agree	agree	disagree	strongly disagree
• It helps keep the children active and busy, discussing and thinking.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
• Pictures are very abstract and have too many conventions. Pupils won't be able to make sense of them, even less use them.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
• It introduces the particle nature of matter in a way accessible to Year 8 and Year 9 pupils.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
• A special vocabulary to be learned which is not even scientific and is different from textbooks.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
• The activities are accessible to low ability pupils, and can help ones with language difficulties.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
• The activities offer a challenge to higher ability pupils, to think hard.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
• I don't see how I can find good places for the activities in the existing schemes of work.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
• I don't really see the point of all the work comparing pictures and talking about them. Some practical experiences would be better.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
• It can be used easily alongside existing schemes.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
• It is easy to see how some of the activities could follow practical work, building on it.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
• It helps teachers to find simple ways of talking with pupils about energy and physical and chemical changes.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
• The ideas are fundamental, and can help link together many parts of science, up to GCSE and beyond.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
• The ideas behind it are too general; what pupils need is a lot of interesting particular things to think about.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
• It gets teachers thinking again about ideas they may not have felt very sure about, and helps them sort these ideas out a bit better.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
• It's certainly a different approach to teaching certain things, but I don't see what new ideas it introduces.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

Appendix 7.1

Matches Made in Year 7 First (A) Interviews 'Grouping' Task (1) - Per Group of Pupils

Year 7A Situations	A1	A2	A3	A4	A5
1 scent or after-shave evaporating from the skin	↑	↑		↑	↑
2 ice forming on a pond	↑	↑	↑	↑	↑
3 a cold drink left out in the sun	↓	↑	↑	↑	↓
4 acid rain eroding a stone statue	↑	↓	↓	↓	↓
5 hot lava from a volcano turns solid	↓	↓	↑	↑	↓
6 making soup out of powder soup and water	↓	↑	↓	↑	↑
7 fruit drying in the sun	↓	↑	↑	↓	↓
8 a plant growing	↑	↓	↓	↓	↓
9 a car windscreen being shattered	↓	↓		↑	↓
10 wood burning	↓	↓	↓	↓	↓
11 digesting food	↓	↓		↓	↓
12 a hot bath cools down	↓	↓	↓	↓	↓

Appendix 7.2

Matches Made in the 'Grouping' Task of the Year 7 First (A) Interviews - Per Situation

Situations used in the first (A) Y7 interviews	1 scent or after-shave evaporating from the skin	2 ice forming on a pond	3 a cold drink left out in the sun	4 acid rain eroding a stone statue	5 hot lava from a volcano turns solid	6 making soup out of powder soup and water	7 fruit drying in the sun	8 a plant growing	9 a car windscreen being shattered	10 wood burning	11 digesting food	12 a hot bath cools down
1 scent or after-shave evaporating from the skin	•		A1 A5	A4			A2			A5		
2 ice forming on a pond		•		A2 A5	A1							A4
3 a cold drink left out in the sun	A5		•	A2			A1 A4			A5	A4	
4 acid rain eroding a stone statue	A4	A3		•				A4	A5	A1		
5 hot lava from a volcano turns solid		A1 A5		A2	•					A4		A1
6 making soup out of powder soup and water		A1	A3			•					A4	A5
7 fruit drying in the sun			A5				• A4	A2 A4				
8 a plant growing				A4			A3 A4	•		A2	A1	
9 a car windscreen being shattered		A1 A2		A2 A5					•	A4		
10 wood burning	A5		A5		A2 A3 A4		A1			•		
11 digesting food	A2		A4			A1 A5					•	
12 a hot bath cools down		A3 A4			A1 A5	A2						•

Appendix 7.3

Matches Made in the 'Grouping' Task of the Year 7 Last (D) Interviews - Per Group of Pupils

Year 7D Situations	D1	D2	D3	D4
1 a plant growing				
2 running and using up food				
3 ice forming on a pond				
4 sweating to stay cool				
5 wood burning				
6 acid rain eroding a stone statue				
7 your body making extra fat				
8 a hot bath cools down				

Appendix 7.4

Matches Made in the 'Grouping' Task of the Year 7 Last (D) Interviews - Per Situation

Situations used in the last (D) Y7 interview	1 a plant growing	2 running and using up food	3 ice forming on a pond	4 sweating to stay cool	5 wood burning	6 acid rain eroding a stone statue	7 your body making extra fat	8 a hot bath cools down
1 a plant growing	•		D4				D1 D2 D3 D4	
2 running and using up food		•		D1 D3 D4	D1" D2			
3 ice forming on a pond			•			D4	D1 D2 D3	
4 sweating to stay cool				•				D1 D2
5 wood burning					•	D3		D4
6 acid rain eroding a stone statue					D1 D2	•		
7 your body making extra fat			D4				•	
8 a hot bath cools down			D1	D3				•

Appendix 7.5

‘Matching’ and ‘Comparing’ Tasks: Comparison Across Year 7 Group 2 Interviews

A7.5.1 Concentration change: Matter ‘spreading out’ and ‘bunching together’

A7.5.1.1 ‘Spreading out’

Unlike Group 1, the pupils of Group 2 made extensive use of the term ‘spreading out’ in the first interview. They used it in their accounts of six out of the eight changes presented to them. My impression is that they applied it loosely without differentiating its meaning in different contexts. So, they said that “the hot is going to spread out in the cold drink” which is left out in the sun, that the leaves and branches of ‘a plant growing’ spread out, but also that carbon dioxide spreads out when wood is burning. They also thought that the phrase ‘something is spreading out’ is true for ‘ice forming on a pond’ and for ‘hot lava from a volcano turns solid’. The explanations they gave however for these choices show that they rather referred to the behaviour of snow falling and of lava coming out of a volcano respectively and not to the given changes. This tendency to shift the focus from the changes given to other changes related to them was also reported in the analysis of task one (‘grouping’) of the first interviews (see subsection 7.2.2).

In the second interview five out of the eight changes were matched by one or more pupils to the abstract picture ‘spreading out’. The two that would have been appropriate matches were eventually rejected. On the other hand two matches, which I think of as inappropriate, were retained; the thing that was said to be ‘spreading out’ was heat. The situation ‘your hair growing’ was matched to ‘spreading out’ for the same reasons as Group 1. Moreover, as with Group 1, the word ‘separate’ was used in two cases instead of that of ‘spread out’ as its synonym, e.g. “*when the car explodes it separates and bits come out from it*”. I have mentioned in the pupil case studies why the confusion of these two words is undesirable for the project. The use of the term ‘separate’ to mean ‘spread out’ becomes problematic not only because of its ‘macroscopic’ connotations, but also because in the project the term is used as synonym of ‘unmixing’. This point is best exemplified in the ‘comparing’ (third) task of this second interview. There the situations ‘cleaning a paint brush in water’ and ‘an explosion’ were said to be similar because in the first “*the paint is separating from the brush*” and in the second “*when it blows up all the pieces separate from the car*”. In other words, for the first situation the word ‘separate’ is used with the meaning of ‘unmixing’ while for the second it is used with the meaning of ‘spreading out’. And ‘unmixing’ appears in the project materials as a process that leads to the ‘bunching together’ of substances and not to their ‘spreading out’.

In the third set of interviews ‘spreading out’ was chosen as a match for seven out of the eight situations. As with Group 1 the pupils were by now a lot more familiar with the use of the term. The notion that ‘hotness’ spreads out in the situation ‘a cold drink left out in the sun’, a notion which also appeared in the first set of interviews, was still present in the third one, but this time it was rejected. However the conceptualisation of fire as a substance which spreads out in connection with the situation ‘wood burning’, also present in the first set of interviews, was retained. As with Group 1 the least appropriate matches in the end got rejected. Moreover, similarly, the more sophisticated use of the word occurred in relation to the change ‘smoke filling the air over a city’, a change previously met in their lessons.

The link of 'spreading out' to the process of evaporation, observed in the corresponding interview with Group 1, was not apparent in the interview in question. There was no indication that the term 'spreading out' was used except in macroscopic descriptions of the changes.

In the fourth interview the idea of 'spreading out' was applied to six out of the eight situations. From the less appropriate matches only one was kept and this was the match of 'a plant growing' to the abstract picture of 'spreading out'. This match was challenged strongly at the beginning by one pupil and subsequently by another who thought that the appropriate match was to the 'bunching together' picture. The debate that arose was intense. As in the first interview, the leaves and branches but also the water inside the plant was seen as spreading out. Lack of a microscopic perspective did not permit the pupils to accept the 'bunching together' option despite the fact that one pupil arrived at saying that:

"...this bunching together..., it's just for one second it's bunching together, but then when it grows up it... spreads out - its leaves - and grows..."

Also 'ice forming on a pond' was - as in the first interview - matched to 'spreading out' by one pupil. This time it was not because of snow falling, but because ice was seen to spread out over the lake. In the end the pupil accepted that ice *"bunches together to spread out"*. On the other hand another pupil was persuaded that matching the situation 'running and using up your food' to the picture of 'disappearing' was more appropriate than matching it to that of 'spreading out' which was her initial choice.

The most sophisticated applications of 'spreading out' was for one of the changes previously discussed in the classroom, namely that of 'sweating to stay cool':

"Because the water spreads, and comes out and it spreads out in the sky."

Finally in the 'comparing' task when the interviewer asked if anything 'spreads out' in either of the situations 'wood burning' or 'running and using up food', the idea that fire 'spreads out' resurfaced although another pupil corrected it by saying that *'wood is burning and spreads out'*.

A7.5.1.2 'Bunching together'

The pupils - same as in Group 1 - did not have any problem identifying the 'freezing' changes of state as 'bunching together' processes. On the whole they made use of the term much more than the pupils of Group 1 right from the first interview. However, with the exception of the freezing changes, the term was used inappropriately for macroscopic descriptions of the situations given or somehow related to these changes. For example, for 'wood burning' it was imagined that *"the flames might come together and form one"* if the wind blew, and thus 'something bunches together' was a statement true for the change. It is even more problematic perhaps that they saw mixing powder soup and water as a bunching together process as *"it all comes together and make one"*, considering the way the project's materials - not yet studied by the pupils at that stage - talk about mixing as a 'spreading out' process.

In the second interview the term was always used appropriately, in relation to the situations 'crystals forming in copper sulphate solution as it cools' and 'the windows of the car misting up on a very cold day'. The other 'unmixing' change, namely 'purifying water', two of the four pupils preferred to match to the 'unmixing' abstract picture and the rest to the 'no change' picture.

In the third interview 'bunching together' is used in relation to four situations but only appropriately for two. These two, 'water vapour forms clouds' and 'getting salt by evaporating salt solution' are changes one would expect them to get right as they

had been covered by previous teaching. Having said that, it is unclear to me why they matched the changes 'a cold drink left out in the sun' and 'wax melting' to the 'bunching together' picture because in the first case the reason given is that *"the water is disappearing, turning to steam"* and in the second one that *"the wax is bunching up and melting"*. However, I suspect that these two reasons were given by the same pupil who might have incorrectly understood the meaning of 'bunching together'. Unfortunately, neither of the two suggestions was rejected. Moreover, the same idea, that *"the drink is bunching up while it is getting hot"* appears again in the 'comparing' (third) task of the same interview.

As with Group 1, what is clearly different in the fourth interview is that the changes of 'growing' such as 'plant growing' and 'your body making extra fat', which in the previous interviews were described mainly as 'spreading out' events, this time were talked about as 'bunching together' processes. Some of the explanations given however for these matches show that some of the children had accommodated rather than assimilated this new use of 'bunching together'. For example, the situation 'your body making extra fat' was matched appropriately to the picture 'bunching together' but one of the reasons given for this match was not so appropriate:

"Because the food when it gets to your tummy I don't think it goes everywhere - it just stays in your tummy..."

A7.5.2 Physical change: Matter 'mixing' and 'un-mixing'

In interview A the phrase 'something is mixing' was used in relation to six out of the eight situations. The term 'mixing' before the relevant instruction took place seemed to be used loosely - when two things were thought to be interacting. So, while on the one hand sugar was thought of as being mixed into the coke and powder soup was said to be mixing with water when soup is made, on the other hand fire and wood, sun and drink and hot and cold were said to be mixing when wood is burning, a cold drink is left out in the sun and a hot bath cools down respectively. On these occasions heat (and its opposite coldness) and fire were treated as material substances. This was also noted in the use of spreading out as well as in the analysis of Group 1 interviews. In the case of 'wood burning' one could see how a teacher could make use of the fact that children are thinking in terms of two things mixing to introduce the role of the oxygen in burning.

The phrase 'something is unmixing' was not used by the pupils in interview A.

The pupils used the abstract pictures of 'mixing' and 'unmixing' in relation to all three relevant changes; they had previously discussed these changes in their lessons. So, 'cleaning a paint brush in water' and 'purifying water' were appropriately matched by the same two pupils to the pictures of 'mixing' and 'unmixing' respectively. In both cases the substances that were mixing or 'unmixing' - the pupils preferred to use the term 'separating' in their explanations - were identified. The two other pupils made use of the picture of 'mixing' only, to which they matched inappropriately the situation 'crystal forming in copper sulphate solution as it cools'. The reason given for this match is not very clear. However in the third ('comparing') task of this interview they said for the same change:

P1: "Copper sulphate and water has to mix together to make a crystal."

P2: "Liquid and these blue powders..."

In the above explanation the term 'mixing' was used desirably. The pupil must have been referring to the making of copper sulphate solution rather than to the formation of crystals. The pupils had experienced both of these changes in a practical they had done in one of the science lessons that had preceded.

A7.5.3 Chemical change:

'A substance changes' - 'It makes a new substance'

As opposed to Group 1 pupils, Group 2 pupils did not make use at all of the phrase 'a substance changes' in the first interview. One reason for this could be that they were not familiar with the term 'substance'; one pupil asked the interviewer to explain the term before they first used it. While they did not make use of the phrase 'a substance changes', in three cases they rejected the phrase 'substances stay the same'. For 'a drink left out in the sun' they reasoned on the basis of their own experience with drinking Coke that *"it might go flat after you leave it"*. The situations 'ice forming on a pond' and 'hot lava from a volcano turns solid' on the other hand involved changes of temperature and of state, so the phrase 'it makes a new substance' was seen as more suitable to them. As in Group 1, for both situations the identification of the change of state was in concrete terms at the level of object. Moreover, for the same reasons given also by the Group 1 pupils the situations 'wood burning' and 'a plant growing' were said to be making a new substance.

In the third interview, a change of temperature and of state was still thought of as a change of substance. Similarly to what was observed in the Group 1 interview evaporation and condensation were seen as processes which result in the making of a new substance, while melting was not. From the explanation they gave in defence of this for 'wax melting':

"When the wax melts, when it gets solid, it becomes wax again."

one can hypothesise that melting did not present the same difficulties with the other changes of state because its reverse process - that is, freezing - could be more readily imagined by the pupils.

In the final interview (D) the pupils' answers did not seem considerably altered as compared with the first. When they perceived a new 'object' as being made, no matter if its substance was the same, the pupils reasoned that a new substance was made. Chemical changes presented the same difficulties to this group as to Group 1. Confusion arose when the pupils could not name the participants of a change, as for example in the situation 'your body making extra fat'. One pupil argued that as one eats one's tummy changes size, but not substance, while another implied that the process of growing involves the making of new substances, which however s/he could not name. No agreement was also reached for the change 'sweating to stay cool'; the dilemma there was whether water can be called a new substance albeit the fact that it exists prior to the change in the human body.

A7.5.4 Maintaining a concentration difference

A7.5.4.1 'Substances stay the same' - 'No change'

The use of the phrase 'substances stay the same' in the first interview has been already discussed above.

The equivalent picture 'no change' was chosen as a match for three out of the eight situations in the second interview by one or more pupils. It was not chosen as a match for the situation 'an electric iron cools down' even though it would have been appropriate to do so. For the situation 'warming your hands by the fire' - the second of the intended matches - there was some discussion about whether change of temperature constitutes change of substance. Although the situation was eventually matched to the picture of 'spreading out', it is worth noticing that three out of the four pupils had originally matched it to the 'no change' picture. Moreover, interestingly enough, the situation 'purifying water' was matched by two pupils to the 'no change' picture. It is not very clear, however, from the justification given if the substances were seen as not changing in the 'unmixing' process. This match was retained. Finally, the 'no change' picture was also chosen by one pupil for 'your hair growing'. This is another case in which the participants of the change could not be

named by the pupils; in my opinion this might have led the pupil in question to reason that when your hair grows there is no change in substances. The rest of the pupils objected to this suggestion and the match was discarded.

In the third interview the pupils correctly identified the situations which did not involve a change in matter. These were 'a cold drink left out in the sun', 'your body staying warm on a cold day' and 'warming your hands by the radiator'. Furthermore they explained that 'no change' meant that there was no change in the concentration of matter; a situation which involved merely temperature changes could be matched to the 'no change' picture. In their own words, for 'your body staying warm on a cold day' they said:

"It stays like the same and there's no change. [...] Like it doesn't spread out or bunch together."

and for 'a cold drink left out in the sun':

"There is no change in the drink - it is just getting warmer."

No situation was matched to the 'no change' picture in the fourth interview. The situation that was intended by the design of the interview to be matched to it - 'a hot bath cools down' - was matched to the picture of 'disappearing'; heat or hot air from the bath was seen as disappearing.

A7.5.4.2 'Keeping a balance'

The idea of 'keeping a balance' was discussed only in relation to the changes 'sweating to stay cool' and 'a hot bath cools down'. In both cases the match was rejected. In the first case, its use implied some kind of flow of matter - a person loses water but also replaces it by drinking more:

"You have the same amount inside. [...] It goes out and then it goes in. You drink more and you sweat."

In the second case however, the idea was used to express the absence of change in the amount of matter perceived statically.

"The heat changes and it becomes cool, but the level of the water - the balance of the water stays the same..."

The above pupil further rejected the idea that evaporation is taking place when a hot bath cools down. Both these uses were also met in the Group 1 interview.

A7.5.5 Temperature change

A7.5.5.1 Phrases: 'Something gets colder or less hot' - 'Something gets warmer' - 'Temperature evens out'

Just like the Group 1 pupils, the pupils of Group 2 eagerly and mostly appropriately applied either of the phrases 'something gets colder or less hot' or 'something gets warmer' to the situations presented to them in the first interview. The surroundings was mentioned only in relation to the situation 'a cold drink is left out in the sun' when this was identified as a warming up change.

From its use, it is not clear what was understood by the expression 'temperature evens out'. As with Group 1 and as before, for all six situations to which it was applied the temperature of the surroundings was ignored while the temperature of the system was seen as changing. In the case of 'wood burning' the idea of temperature evening out was associated with the spreading out of heat. The phrase could have been also matched to further two situations.

A7.5.5.2 Picture: 'Difference in temperature disappears'

In the third interview the abstract picture 'difference in temperature disappears' was chosen as a match for seven out of the eight situations, by one or more pupils; for six of them the match was appropriate. As also mentioned in the analysis of the equivalent interview for Group 1 and contrary to what was observed in the first interview, in all the justifications the pupils gave for the matches they made the temperature of the surroundings at the start of the change was identified as well as the temperature of the system; often the temperature of the system was specified relatively to that of the surroundings or vice versa. I take this as evidence that the pupil identified a temperature difference between the system and its surroundings. I also make the same assumption for the use of a temperature contrast in an explanation, as for example in

"The hand is cold and the radiator is hot and then they become the same temperature."

What is interesting is that whereas sometimes it was left to be implied which temperature was changing during the process, it was declared unequivocally that at the end of the change the temperature of the system was the same as this of the surroundings. Furthermore, this was in all cases expressed at a generic level as in the example above.

Just as in Group 1, the temperature difference between the system and its surroundings was never as such explicitly said to be the cause of the temperature change observed.

A7.5.5.3 Picture: 'Difference in temperature appears'

As in Group 1, the abstract picture 'a difference in temperature appears' presented considerable problems to the pupils. It was applied to six out of the eight situations but it was not finally kept as a match for any of them. It was actually chosen as a match 12 times; from these matches one was not justified, three, which appeared at the beginning of the interview, showed that the pupils had not understood the picture, two were rejected by the pupils who made them without explanation, and for another four the explanation was not very clear. As in Group 1, the definition of the 'Before' and 'After' instances was a source of confusion, especially for the changes 'wood burning' and 'getting salt by evaporating salt solution'. In these changes the pupils seemed to define 'Before' as the instance at which the change has started and 'After' as the instance at which the change has been completed, that is, when all the wood has been burnt and all the salt has been extracted. The problem with this definition is tracing the temperatures of the system and its surroundings 'Before' and 'After'. The pupils seemed to focus primarily on what is happening to the temperature of the system; this is the same as its surroundings at the start and changes 'After'; what is happening to the temperature of the surroundings 'After' was not specified. So, for 'wood burning' they said:

"When they are burning they [the wood and the fire] are the same temperature and when it is finished burning the wood goes colder."

Furthermore, some pupils seemed to interpret the expression 'a difference in temperature appears' literally to mean 'something appears', especially at the start of the interview. For 'getting salt from evaporating salt solution' one pupil said:

"First they both are the same temperature - the salt and the water. And then, when... water disappears - something appears - that's the salt that appears. And all the salt bunches together."

A7.5.6 Maintaining a temperature difference

A7.5.6.1 'Temperature stays the same' - 'No change'

Similarly to Group 1, the expression 'temperature stays the same' was not chosen for any of the situations presented to them in the first interview.

In the third interview the picture 'no change' was selected as a match to three situations and was retained only for the situation 'wax melting'; in no case was it an appropriate match. In all cases the pupils did not seem to interpret correctly what the abstract picture showed but rather seemed to respond to its linguistic prompt. For the situations 'wax melting' and 'your body staying cold on a cold day' they merely identified an absence of change in the temperature of the system, while for the change 'a cold drink left out in the sun' which appears towards the start of the interview one pupil interpreted the picture to mean 'no change of substance'.

A7.5.6.2 'Difference in temperature is maintained'

As for the picture 'difference in temperature is maintained' the pupils chose it correctly for the situation it was intended, namely 'your body staying warm on a cold day'. The reason they gave was that there was no change in either the temperature of the system or the temperature of its surroundings, implying thus that the temperature difference which existed in the 'Before' instance continued to exist 'After'. However, for the situation 'a cold drink left out in the sun' one pupil identified a temperature difference 'Before' and a temperature difference 'After', but also talked about the system's temperature changing "*from cold to warm*" - the sun was said to be always hotter than the drink. In other words the temperature difference was not seem as being maintained during the change. A similar observation was made for Group 1.

A7.5.7 Spontaneous and non-spontaneous change

A7.5.7.1 'It happens by itself' - 'Someone makes it happen'

The findings concerning the use of the phrase 'it happens by itself' by the pupils in the first interview are identical with the ones that emerged from the analysis of the Group 1 first interview. The phrase was interpreted to mean the absence of an agent in a change and sometimes more particularly the absence of a human agent. So it was easily employed in the description of physical changes but also for the description of changes which made reference to a natural phenomenon. The pupils thought of the situation 'acid rain eroding a stone statue' for example, as happening by itself because "*acid rain just comes down*".

The phrase 'someone makes it happen', as in the Group 1 interview, prompted the children to identify a human action which is responsible for the change by either setting the scene for it to happen or by causing it directly. For the situations 'a hot bath cools down' and 'a cold drink left out in the sun', for example

"Someone makes the water go in the bath, and someone pours the drink into the cup."

Thinking in this way it was not difficult to reason for one situation that both 'it happens by itself' and 'someone makes it happen'.

These two phrases were not used in the 'comparing' task of the second (B) interview as with the Group 1 pupils due to lack of time.

In the third interview the use of the expression 'it happens by itself' appeared slightly more sophisticated. In the first instance, the pupils seemed to have realised that the phrase refers to the process involved in a change and not to how this process is set going. For 'wood burning' for example, this time they said:

"Yes, that does. Because people just lit it maybe and it burns - and then people are not making it burn - it burns by itself."

Furthermore, an interesting discussion arose about whether the situation of a human body staying warm on a cold day involves processes of change that don't just happen by themselves.

"You have to make your body hot with something. [...] It's just forming your body to get warm, isn't it?"

said one pupil clumsily. What s/he meant is not clear, but one could see how this could be taken further by a teacher teaching about homeostasis.

A7.5.7.2 'It is easy to reverse the change'

The use of the phrase 'it is easy to reverse the change' reveals the same issues already discussed in the analysis of the Group 1 interviews. Only this time the expression was not employed in the description of the two changes of state - 'ice forming on a pond' and 'hot lava from a volcano turns solid' - in the first interview. In other words, to 'reverse' a chemical change for these pupils (as well) seemed to mean to stop an event from happening or rather not to let it happen in the first place, both of which imply the intervention at some point of a human action. Furthermore the easiness of the reverse process depends on what is humanly easy and controllable. 'A plant growing' was seen as a change which is hard to reverse because

"...like suddenly rain happens. It can get water from the rain. It would take quite a long time for the plant to die."

In the fourth interview there were more attempts to reverse the change in the situations given. In some of them the suggested reverse changes were nothing more than events which aimed at eliminating the results of the original events. For example for the situation 'sweating to stay cool' the suggested reverse situation was to drink more water; in this neither the identity of the participants is retained nor the reverse path is followed. However, with the help of the interviewer, it was reasoned that it is not easy to reverse the change 'wood burning' as one cannot get the wood back after it is burned. There was almost no difference (compared to the first interview) in the way the pupils talked about reversing the change 'a plant growing'.

Appendix 7.6

'Matching' and 'Comparing' Tasks: Comparison Across Year 7 Group 3 Interviews

A7.6.1 Concentration change: Matter 'spreading out' and 'bunching together'

A7.6.1.1 'Spreading out'

The term 'spreading out' was chosen by the pupils in relation to five situations in the first interview. Its use by the pupils was similar to what has been previously reported for Groups 1 and 2. Similarly to Group 2 pupils, they thought that lava and fire spread out in 'hot lava from a volcano turns solid' and, similarly to Group 1, that ice spreads out on a pond. They also talked about something spreading out in relation to the situations 'a cold drink left out in the sun', 'a hot bath cools down' and 'making soup out of powder soup and water'. Their explanations for the two first indicated that they had not focused on the changes in question; the third match was not justified.

In the second interview six out of the eight changes were matched by one or more pupils to the abstract picture 'spreading out'. Only one match was finally retained; it was of the situation 'an explosion'; it was the intended match although 'spreading out' was seen as happening macroscopically. The picture of 'spreading out' was selected for the situation 'your hair growing' for the same reasons as in Group 1. The ideas that fire and heat spread out surfaced in this interview as well, in relation to the situations 'warming your hands by the fire' and 'an electric iron cools down'. I found unfortunate that one pupil matched the picture of 'spreading out' to the situation of 'crystals forming in copper sulphate solution as it cools' because they had studied this change in their lessons. The pupil apparently reasoned in this way based on the impression the schematic picture of the situation made to him/her. He said:

"Because you know, all those dots are spreading out, so I put they're spreading out."

referring I think to the crystals drawn as dots on the picture.

The other situation which they had discussed in their classroom and which could have been matched to this picture was 'cleaning a paint brush in water'. This was matched to the abstract picture of 'mixing' which was also an appropriate match. Having said this, in the 'comparing' (third) task when the pupils were asked to compare the situations 'cleaning a paint brush in water' and 'an explosion' they came up with 'spreading out' as the similar process happening in both:

"If you wash your paintbrush in water it spreads the dirt from the paintbrush, and if you get a car crash, all the wheels and things drop on the floor and spread out all over the place."

In the third interview the picture of 'spreading out' was chosen by one or more pupils as a match for every one of the eight situations; it was eventually retained as a match for five situations; it was an appropriate match for two. The ideas that 'heat' and 'fire' spread out were also present in this interview - see analysis of Group 2 - and were responsible for the matches of the situations 'warming your hands near the fire', 'wood burning' and partially of 'getting salt by evaporating salt solution'. For the latter I had the impression that the pupil who mentioned it was referring to the vapour that comes out of the salt solution as water evaporates. Similarly, for the situation 'water vapour forms clouds' the children focused rather

on the process of evaporation, and thus reasoned that “*water is spreading out*”, than on the process of condensation which was the intended focus. Another confusion, also reported for Groups 1 and 2, surfaced in this interview as well; the use of ‘separating’ as a synonym of ‘spreading out’. A pupil reasoning about the extraction of salt from salt solution saw the salt separating and spreading out. The salt is indeed separating or ‘unmixing’ in the language of the project, but it is not spreading out. As with the other groups the situation ‘smoke filling the air over a city’ was unproblematically spoken of in terms of ‘spreading out’.

In relation to the situation ‘melting wax something interesting happened. Three out of four pupils had matched it to the picture of ‘bunching together’ and one to that of ‘spreading out’. All without exception however, spoke of wax spreading out as it melts, they did not think however of this as the final stage of the change; they then saw wax bunching together as it cools down. This reasoning was so powerful that even the pupil who had originally chosen the ‘spreading out’ picture changed his mind. However, in the ‘comparing’ (third) task the pupils did not hesitate to reason that ‘melting wax’ and ‘wood burning’ were similar changes because in both of them something is spreading out.

In the fourth interview the use of ‘spreading out’ was significantly more desirable seen from the project’s point of view. It was matched to six situations, but it was finally retained as a match of the four it was intended for. The effect of the teaching that had preceded was evident; only one pupil - one of the least able of the class - matched the situation ‘your body making extra fat’ to the picture of ‘spreading out’, whereas three out of four pupils matched the situations ‘running and using up food’ and ‘sweating to stay cool’ to it. In every case the odd choice was rejected and the pupil who made it was convinced otherwise. Moreover, as noticed in Group 2, the use of ‘spreading out’ was noticeably more sophisticated in relation to the changes previously studied. For ‘running and using up food’ the pupils argued that:

P1: *“When you are running and you’re sweating, you get rid off water, like then it spreads out the water inside your body.”*

P2: *“And then it goes out and spreads out in the air.”*

Although the intended focus for this situation was the food and what is happening to it, the pupils adapted the situation to what they had met in their lessons and were confident with, that is to the evaporation of water from the human body.

About the match of the situation ‘wood burning’ to the ‘spreading out’ picture the pupils explained consistently with previous interviews that fire spreads out. They also referred to fire mixing with the air (see under ‘mixing’). However, in this interview, a pupil did not fail to notice that “*wood is spreading too on the fire*”. As for the other chemical change ‘acid rain eroding a stone statue’ although there was a considerable disagreement between the pupils as to whether it should be matched to the ‘bunching together’ or to the ‘spreading out’ picture, I thought that the arguments presented in favour of each case were of the sort a teacher would desire his/her pupils to have before s/he introduced them to chemical change. The pupils spoke of the statue melting and dissolving and wondered whether acid rain bunches together with the statue while it is melting. The pupils that were in favour of the ‘spreading out’ match insisted that in melting or breaking the statue cannot but spread out.

A7.6.1.2 ‘Bunching together’

The phrase ‘something bunches together’ was not selected by the pupils in the first interview.

In the second interview the abstract picture of ‘bunching together’ was matched to three situations, only to one appropriately. Only the appropriate match was retained after the discussion. Contrary to what has been noted for Groups 1 and 2 it was not

chosen for the situation 'crystals forming in copper sulphate solution as it cools'. As for the situation 'purifying water' this group did not match it to either the 'bunching together' or the 'unmixing' (choice of Groups 1 and 2) picture, but rather to the 'disappearing' one. Furthermore, for 'cleaning a paint brush in water' one pupil associated 'bunching together' with the process of mixing, contrary to what she had been taught. Even in the case where the pupils matched the picture appropriately, that is in relation to 'the windows of the car misting up on a very cold day' it was not clear whether they perceived 'bunching together' in the desired way.

In the third interview, the picture of 'bunching together' was chosen in relation to four situations, only for 'getting salt by evaporating salt solution' appropriately. However, this match was not retained, while two other less appropriate (to 'a cold drink left out in the sun' and to 'melting wax') were.

Looking in more detail at how they used the term, I noticed that in two occasions they used it to describe a state rather than a process. What I mean is shown in the following quotation about 'smoke filling the air over a city':

"It's like when it comes through that thing there it is all squashed like bunched together, and then it spreads out."

Here we see that with 'bunched together' the pupil described the appearance of the smoke before it spreads out, that is, how it is / looks like and not what it is doing or what is happening. Again for 'a cold drink left out in the sun' one pupil reckoned that:

"The drink inside is all bunched up together - it is not spread out."

As for the situation 'wax melting' (see under 'spreading out') the pupils reasoned that wax bunches together not when it is melting but while it cools down, that is after the end of the change.

Similarly to what was observed with Groups 1 and 2 and with the use of 'spreading out' in the previous section, the use of 'bunching together' in the fourth interview seemed significantly enhanced. Not only because on the whole they made appropriate matches; it has already been noted for Group 2, that in relation to the changes of biological growth some of the pupils made the appropriate choice of abstract picture but gave justifications that showed that they had merely assimilated, as opposed to accommodated, the idea. But because in two instances pupils seemed to spontaneously generalise at a fairly high level of abstraction about the use of 'bunching together'. A child, for example, explaining why s/he chose to match 'a plant growing' to the 'bunching together' picture said:

"Like your body gets growing. That's why I pick it."

With this phrase s/he both acknowledged that a plant growing and a human growing are essentially similar - something not necessarily obvious -, and declared silently as obvious / common knowledge that the 'growing' of a human body involves a 'bunching together' process. Another pupil said about 'ice forming on a pond', when s/he saw one of her/his classmates matching it to the abstract picture of 'disappearing':

"How can it be disappearing? Like it's forming - it's bunching to start grow. It's going to form and grow. Form and grow is the same thing. So it's going to bunch."

Here s/he took as given that 'growing' is a 'bunching together' process, she abstracted that forming and growing are essentially the same, and thus reasoned that when ice forms something is bunching together. From the previous groups I have concluded that the children quite readily accepted that 'freezing' can be perceived as a 'bunching together' process, sometimes even before any teaching occurred.

Interestingly, however, in the previous example, the pupil seemed to deduct this more commonsensical idea from a less obvious one, namely from the thesis that 'growing' is about 'bunching together'.

A7.6.2 Physical change: Matter 'mixing' and 'un-mixing'

'Something is mixing' was used in the first interview in the same way as has already been described for Group 2. The pupils chose the phrase for five out of the eight situations. Its use was very broad and more often not the intended one. The idea that hot and cold mix is met once more in their discussions. As this group consists of less able pupils than the previous two groups we meet even less appropriate uses; for example 'something is mixing' was said to be true for the situation 'ice forming on a pond' because *"ice is mixed with water"*. It is not very clear to me what they meant by this.

The phrase 'something is unmixing' was not chosen by the pupils in interview A.

In the second interview the abstract pictures of 'mixing' and 'unmixing' were used for five out of the eight situations; including the three for which they were intended to be used. The idea that wood and fire mix surfaced again as with Group 2 (see also under 'spreading out' for interview D), only this time in relation to the situation 'warming your hands near the fire'; the match however was eventually rejected. Also the situation 'an electric iron cools down' was inappropriately matched by one pupil to the 'mixing' picture and by another to the 'unmixing' one. Neither match was finally retained.

For situations which had been studied in the classroom the use of the above ideas was more satisfactory although not always appropriate. As with Group 2 the situation 'crystals forming in copper sulphate solution' was matched to the picture of 'mixing' by two pupils. Although the match was inappropriate, the use of the term 'mixing' in the explanation one pupil gave was not.

"Because it is mixing, crystals mixing with copper sulphate. And then it turns into a solution. This is mixing and then it turns into a solution - that is why I chose that."

I suspect that, as in Group 2 interview, the pupil was referring to the making of copper sulphate solution rather than to the formation of crystals. The situation 'cleaning a paint brush in water' was easily matched to the 'mixing' picture, and the substances participating in the process were named. The situation 'purifying water' was unsuccessfully matched first to the picture of 'mixing', then to this of 'unmixing' by the same pupil. From the justifications attempted I am tempted to conclude that the pupil did not hold a sound understanding of 'unmixing'.

A7.6.3 Chemical change:

'A substance changes' - 'It makes a new substance'

The phrase 'a substance changes' was chosen only in relation to one pair out of the four pairs of situations presented to the children in the first interview. For 'a cold drink left out in the sun' the opinions were split as to whether a substance changes; no justification was given however, for either of the two opinions. When a hot bath is cooling down, however, it was agreed that a substance changes - from hot to cold.

The phrase 'it makes a new substance' was not used for any of the eight situations in the first interview.

In the third interview changes of temperature were again considered as changes of substance. The difference here from the other Groups is that the process of melting was seen as resulting in the making of a new substance. In defence of this

proposition the pupils explicitly stated that they regarded changes in concentration as changes in substance - for 'wax melting' they said:

"Because at first, it's spreading, then afterwards it is bunched together when it goes to the bottom."

In the fourth interview while still the expression 'it makes a new substance' presented difficulties - a pupil had to be reminded what 'substance' means -, it was encouraging to see that the situations 'sweating to stay cool' and 'ice forming on a pond' were said not to make a new substance. Unfortunately, these statements were not elaborated, and thus not much can be said about whether they were the product of a deeper understanding.

A7.6.4 Maintaining a concentration difference:

A7.6.4.1 'Substances stay the same' - 'No change'

The phrase 'a substance stays the same' was not used by the children in the first interview for any of the situations presented to them.

In the second interview however, the equivalent picture was chosen as a match for six out of the eight situations by one or more pupils. For three situations, the match was retained; these included the two for which the picture was intended, namely 'warming your hands by the fire' and 'an electric iron cools down after being switched off'. All four inappropriate matches were made by the same pupil, a girl who had learning difficulties; for the change 'your hair growing', in particular, she retained her choice even though the rest of the pupils agreed that it would be better matched to the 'spreading out' picture. In the two appropriate matches two and one pupils respectively identified the temperature change and justified their choice of picture on the basis of the absence of any material change.

In the third interview the 'no change' picture was chosen for two out of the three changes it was intended by design. It was finally retained as a match only to the situation 'your body staying warm on a cold day'. In the situation 'warming your hands by the radiator' heat was seen as spreading out. As to the situation 'a cold drink left out in the sun' the drink was said to be bunched together or to be bunching together with the sun to get hot.

In the fourth interview the only situation that was attempted to be matched to the 'no change' picture was the situation 'a hot bath cools down', but the attempt was not successful. The difficulties the attempt faced were on the one hand the psychological difficulty posed by the verbal prompt 'no change' that titled the picture, and on the other the fact that the pupils thought of steam as spreading out from the hot bath. The first difficulty is exemplified in the following quotation:

"It's not really 'no change'. Hot and cold, but we are talking about other things."

The identified temperature change made it difficult for the children to accept a 'no change' choice of picture, even if that refers only to material changes.

A7.6.4.2 'Keeping a balance'

The abstract picture of 'keeping a balance' was not used by the pupils in the fourth interview.

A7.6.5 Temperature change

A7.6.5.1 Phrases: ‘Something gets colder or less hot’ - ‘Something gets warmer’ - ‘Temperature evens out’

Just like the Group 1 and 2 pupils, the pupils of Group 3 eagerly applied either of the phrases ‘something gets colder or less hot’ or ‘something gets warmer’ to the situations presented to them. However, they seemed not to apply them with the same ease as the other groups; some of the matches, although appropriate, were followed by arbitrary and unclear explanations. The wording of the phrase ‘something gets colder or less hot’ created some confusion as the pupils did not always understand that the terms ‘colder’ and ‘less hot’ are synonyms and thus express the same idea. Similarly to the other two groups, the surroundings and its temperature were not said to play any role in the identified temperature changes with the exception of the sun in the situation ‘a cold drink left out in the sun’ which was said to be the agent of the warming up change.

The pupils did not seem to understand the expression ‘temperature evens out’; they tried to use it once in relation to the situation ‘a hot bath cools down’ without success.

A7.6.5.2 Picture: ‘Difference in temperature disappears’

The abstract picture ‘difference in temperature disappears’ was chosen as a match for all eight situations by one or more pupils. Only five of these matches were eventually retained ; all are considered appropriate matches. For most of the matches, similarly to what was said for Groups 1 and 2, the surroundings was identified. The focus was on that the system and the surroundings end up the same temperature - expressed at a generic level - even if the temperatures they started off with could not be concretely identified. For ‘smoke filling the air over a city’, for example, one pupil argued that a difference in temperature disappeared:

“Because smoke spreads out, and like the temperature of the sky might be warm, cold, warm or cold, and it might be cold so them two would go together - into the same temperature.”

However, even in the situations in which a temperature difference was said to disappear, this was not acknowledged to drive the temperature change. Moreover, for the situation ‘a cold drink left out in the sun’ the pupils - same as in the first interview - expressed the view that *“the sun is making the drink [become] the same temperature”*.

A7.6.5.3 Picture: ‘Difference in temperature appears’

The abstract picture ‘difference in temperature appears’ was matched only to three situations by one or more pupils; all matches were finally rejected. The problems the pupils faced using this picture have been already recounted in the analyses of Group 1 and 2 interviews. Out of the six in total attempts to relate the idea of the picture to the situation matched to it, only one got close enough to success. This was of the situation ‘getting salt by evaporating salt solution’. I have discussed elsewhere about the specific difficulties this situation presented to the pupils, namely the definition of the ‘Before’ and ‘After’ instances of the change, as well as the definition of the system and its surroundings. The following extract shows how one child of this group dealt with these:

“The salt and the fire stays the same, then the fire gets hotter and the salt gets colder, I think.”

A7.6.6 Maintaining a temperature difference

A7.6.6.1 'Temperature stays the same' - 'No change'

Similarly to Groups 1 and 2 the expression 'temperature stays the same' was not chosen for any of the situations presented to them in the first interview.

In the third interview, the picture 'no change' was chosen inappropriately in relation to four situations; it was retained only for one - 'wax melting'. However, although the choice of picture was not appropriate for this change, the explanation that followed it described accurately the temperature changes involved:

"The fire makes the wax hot and the wax spreads out. They stay the same temperature - no changes."

Same as with Groups 1 and 2 the idea of 'no change' was applied to mean that there was an absence of temperature change in the system as in the case of the situation 'your body staying warm on a cold day'.

A7.6.6.2 'Difference in temperature is maintained'

As for the picture 'difference in temperature is maintained' it was selected for five situations and was retained for two. In most of the justifications the pupils referred to a temperature difference between the system and its surroundings 'Before' and 'After' - expressed at a generic level -, but did not define clearly what they considered these instances to be, making it difficult to say whether the matches were appropriate or not. For example, they concluded that the situation 'getting salt by evaporating salt solution' would be better matched to the abstract picture of 'temperature difference is maintained',

"Because first the salt and the thingy is same, I mean different and then afterwards it is still different."

Whereas one could see that the match though not the intended it one, nor the most appropriate, may be possible - a constant temperature difference between the salt solution and the source of heat drives evaporation and the bunching together of salt -, the way the explanation was formulated it is quite unclear what it referred to.

A7.6.7 Spontaneous and non-spontaneous change

A7.6.7.1 'It happens by itself' - 'Someone makes it happen'

About the use of the expressions 'it happens by itself' and 'someone makes it happen' in the first interview of Group 3 the findings are in essence the same with these of Groups 1 and 2. In the few cases where the phrases were selected the discussion revolved around whether the change each time in question involved a human action at some point of the process. Interestingly, the only change for which 'it happens by itself' was said to be true was 'making soup out of powder soup and water':

"The soup is getting mixed, so it's getting by itself, it happens by itself. Nobody is making it."

We see here that while the above explanation is satisfactory it is based on the same kind of reasoning as described above, namely that something happens by itself when no person is involved in making it happen.

The pupils did not make use of the phrase 'it is easy to reverse the change' in the first interview.

The phrases 'it happens by itself' and 'someone makes it happen' were not used in the 'comparing' (third) task of the B interview due to lack of time.

The use of 'it happens by itself' by the pupils in the third interview seemed more satisfactory. They were happy to apply it to the situation 'a cold drink left out in the sun' contrary to what they had thought in the first interview. The idea that a human action is necessary in some situations to set the change going was present in this interview as well, but having registered this necessity the pupils easily accepted that 'warming your hands by the radiator', 'wood burning' and 'wax melting' happened by themselves. In one case the phrase 'it happens by itself' was interpreted to mean that there is no agent, animate or inanimate, to act the change. So, for 'water vapour forms clouds' a pupil said:

"The rain happens by itself, but the cloud doesn't form by itself. The vapour forms it."

A7.6.7.2 'It is easy to reverse the change'

The phrase 'it is easy to reverse the change' appeared in the third ('comparing') task of interview D; the pupils were asked whether it is true for the situations 'your body making extra fat', 'a plant growing', 'sweating to stay cool' and 'ice forming on a pond'. They tentatively said that it might be true for 'a plant growing' and contemplated whether it is true for 'sweating to stay cool' and 'ice forming on a pond' without however reaching a decision. They did not elaborate on neither of these suggestions.

Appendix 7.7

Comparison of explanations given by the Year 7 pupils of Group 1 for situations that appear in more than one interview

A7.7.1 Situation 'a hot bath cools down'

This situation appears in the first (A), and the last (D) set of interviews; a similar change was discussed in the study of the topic 'Materials' approximately five months into the intervention and two months before its end.

Common prompts used in the interviews were:

- something spreads out / spreading out
- something bunches together / bunching together
- something disappears or gets used up / disappearing
- substances stay the same / no change

The situation 'a hot bath cools down' seemed straightforward to the pupils right from the first interview. The temperature change involved was given away in the name of the situation and the pupils were quick to identify it. In both the first (A) and fourth (D) interview, no attention was paid to the surroundings and its temperature. As a result the temperature of the system at the end of the change was characterised either on its own using an absolute term, i.e. 'warm' or 'cold', or in relation to its previous state using a relative term, i.e. 'colder'. Importantly while in the first interview the absolute characterisations abounded, in the fourth interview there were only relative ones. Furthermore, in the D interview we see the pupils attempting to relate the process of cooling to the process of evaporation. Asked by the design of the interview to focus on changes in concentration of matter the pupils matched 'a hot bath cools down' to the abstract picture of 'spreading out' and reasoned:

P1: "Because when a hot bath cools down the hot water vapour evaporates..."

P2: "...into the air, and the heat - not disappears but - evaporates into the air, so then it gets cooler, then more heat..."

While the above account of evaporation may not be the most desirable one, the attempt to link causally the observed temperature change of the system with a change in its state and concentration is certainly worth some credit.

A7.7.2 Situation 'ice forming on a pond'

This situation appears in the first (A), and the last (D) set of interviews; a similar change was discussed in the study of the topic 'Materials' approximately five months into the intervention and two months before its end.

Common prompts used in the interviews were:

- something spreads out / spreading out
- something bunches together / bunching together
- something disappears or gets used up / disappearing
- it makes a new substance
- substances stay the same / no change
- it just happens by itself or someone makes it happen it is easy to reverse the change

In the first interview the pupils identified correctly the change of state and temperature occurring to water when ice forms on a pond. However they seemed to treat the change of water into ice more like a transformation which resulted in a new substance than a phase change. This did not stop them on the other hand from reasoning that it happens spontaneously when it snows and that it could be easily reversed if one also reversed the temperature change. Having not had any formal

teaching about the change in question they seem to have moved freely between different levels of explanation. On a further occasion they said that when ice forms something bunches together, but also retained the idea that as it forms it spreads out on to the pond. The second description presupposes looking at the change macroscopically and treating the situation as an event.

In the fourth (last) interview the focus was by design on the material change happening to water as it turns into ice. All the pupils talked about the water bunching together, going hard and turning into a solid. This time when asked if there is anything that is spreading out in the situation they said:

“Nothing is spreading out there - it’s going hard.”

Furthermore, though after some hesitation, they reasoned that no new substance is made in the process:

“It’s water but it’s hard - that’s all. So it doesn’t really make a new substance.”

However, the macroscopic overview of the situation was not completely renounced. One of the pupils having described the phase change of water in terms of it bunching together to form a solid, preferred to match the situation to the abstract picture of ‘keeping a balance’ because:

“...it is still keeping the balance - because there is no water disappearing, it’s just forming a solid.”

Finally, as in the A interview it was perceived that it would be easy to reverse the change, and the reverse process was identified.

A7.7.3 Situation ‘acid rain eroding a stone statue’

This situation appears in the first (A), and the last (D) set of interviews; no similar change was ever discussed in the classroom.

Common prompts used in the interviews were:

- something spreads out / spreading out
- something bunches together / bunching together
- something disappears or gets used up / disappearing
- substances stay the same / no change

No substantial change is expected in the performance of the pupils in relation to this change in the two interviews, because it deals with a chemical process not met by the Year 7 pupils. In the first interview the pupils struggled to reach a consensus about what is happening when acid rain erodes a stone statue. They seemed to try various of the card-phrases to find which might apply to it. In the end they all agreed with only three of these phrases. They agreed that due to the process of eroding the statue is going to disappear and that this constitutes a change of substance. They also agreed that ‘someone makes it happen’, their reason being that acid rain is primarily caused by human activity.

In the fourth (last) interview the pupils reasoned that the statue experiences a process of spreading out which is somehow related to its erosion by the acid rain. It is not very clear, whether the pupils thought that eroding is a spreading out process; it is more likely that they imagined spreading out happening macroscopically as a result of eroding.

A7.7.4 Situation ‘a plant growing’

This situation appears in the first (A), and the last (D) set of interviews; this change was discussed in the study of the topic ‘Life’, which was the last topic to be taught as part of the intervention.

Common prompts used in the interviews were:

- something spreads out / spreading out
- something bunches together / bunching together
- something disappears or gets used up / disappearing
- it makes a new substance
- substances stay the same / no change
- it just happens by itself or someone makes it happen / it is easy to reverse the change

One would expect the situation 'a plant growing' to present more difficulties than other situations. For one, the name of the situation suggests very little as to which process or processes the pupils should choose to pay attention to, compared for example with the situation 'a hot bath cools down'. Moreover, the pupils possess no knowledge of the physical and chemical processes involved in growing; they are introduced to growing as a 'bunching together' process in the last topic - 'Life' - but this happens more or less in limbo and in a way not totally free of macroscopic connotations. Also the class discussion that took place was rather limited, and not very clear, restricted largely to water 'bunching together' in the process of growth.

In the A interview the pupils treated the change as an event. They described the plant growing from a seed as an event of transformation where a new substance is made. A human action was thought of as necessary for the event to start happening - 'someone makes it happen' was found to be true for 'a plant growing'. Also a human action consisting of depriving the plant of the conditions necessary for growing would result in the death of the plant and thus in the reversal of the change as they saw it.

In interview D the situation 'a plant growing' was matched to the picture of 'bunching together'. The pupils attempted to explain this match with the limited knowledge of the situation they had. One pupil talked about "*the goodness inside the plant*" bunching together, another made the point that it was food and not the goodness in the plant that was bunching together. Finally a third one described the plant as retaining its form

"It doesn't spread out anywhere where it wants to - it stays together."

and thus ^{as} bunching together.

Again reversing the change was considered as easy as stopping the plant from growing, or causing its death. Both actions involved human intervention and referred to the event of growing and not to the processes involved in growing.

A7.7.5 Situation 'a cold drink left out in the sun'

This situation appears in the first (A), and the third (C) set of interviews; a similar change was discussed in the study of the topic 'Materials' immediately preceding the third interviews.

Common prompts used in the interviews were:

- something spreads out / spreading out
- something bunches together / bunching together
- it makes a new substance
- substances stay the same / no change
- temperature evens out / diff in temp disappears
- temperature stays the same / no change
- it just happens by itself

This was originally intended to be an example of a thermal change only, and not of a change of state as well. However, the pupils even from the first interview talked about the drink evaporating into gas. The change of temperature observed in the drink was attributed to the existence of the surroundings. However, only in the third interview did this interaction of the system with its surroundings become explicit and was thought of as being in both directions. Again, as in the case of 'a hot bath cools down' discussed above, in the later interview final temperatures were expressed more often in relative than in absolute terms. Moreover, in the later interview the evaporation of the drink was described as a spreading out process.

As to the spontaneity of the change, there was again a slight shift in the way the pupils perceived it in the two interviews. In the first, three out of the four pupils insisted that the sun is the agent of the change, and thus that it does not happen by itself, while in the third interview the sun was perceived as a 'natural' agent which meant that the process does happen by itself, that is, it happens naturally, without human intervention. Human actions were said to have preceded the change, and have set the scene for the change to happen.

As to whether a substance changes, or a new substance is made, the certainty expressed in the first interview, was not so widely shared in the third. While the pupils seemed to conclude in the end that the situation 'a cold drink left out in the sun' entailed the making of a new substance, the doubts which in the first interview were non-existent were voiced quite strongly this time. There was some discussion and a reluctance to reach a definite decision about whether evaporating and becoming gas meant the making of a new substance or not.

A7.7.6 Situation 'warming your hands near the fire / by the radiator'

This situation appears in the second (B), and the third (C) set of interviews; a similar change was discussed in the study of the topic 'Materials', in the interval between the two interviews.

Common prompts used in the interviews were:

- something spreads out / spreading out
- something bunches together / bunching together
- no change (in matter)

'Warming your hands near the fire' was used first in the B set of interviews. It was intended as an example of a thermal change. It was included in the second interview which focused mainly on changes of mixing and unmixing, as a situation of contrast, that is, as a situation that does not involve any material change and which should be matched to the 'no change' abstract picture. However, the pupils saw it as an example of mixing, treating either the fire as a substance which gets mixed with the air or the heat as a substance which gets mixed with the hands in order to cause the observed temperature change.

In order to prevent something similar happening again, in the third set of interviews the picture and name of the situation was slightly altered; it was changed to 'warming your hands by the radiator'. This time it was rightly perceived that there is no material change involved, while there is a difference in temperature which disappears. Both the system and its surroundings were identified and their respective beginning temperatures were expressed in absolute terms. The temperature change observed in the system, expressed as a comparison of before and after states was said to have been caused by the heat contained in the surroundings. As a result of this and of the human intervention envisaged as taking place prior to the change in order for the change to happen, the change was seen as not happening by itself.

A7.7.7 Situation 'wood burning'

This situation appears in the first (A), the third (C) and the fourth (D)(and last) set of interviews; no similar change was ever discussed in the classroom.

Common prompts used in the interviews were:

- something spreads out / spreading out
- something bunches together / bunching together
- it makes a new substance
- something disappears or gets used up / disappearing (A-D)
- substances stay the same / no change
- temperature evens out / diff in temp disappears (A-C)
- temperature stays the same / no change (A-C)
- it just happens by itself or someone makes it happen / it is easy to reverse the change

This was a chemical change used repeatedly in the different sets of interviews. One of the difficulties the pupils had with this situation was to define the Before and

After instances of the change. In interview A, for example, the pupils were happy to apply not only the phrase 'something gets warmer' to 'wood burning' but also the phrase 'something gets colder or less hot'

"Cause after it's burnt up it's going to get colder."

The process of burning was not seen as happening spontaneously; a human action was deemed essential in starting it up. A human action was also seen as necessary if one wanted to reverse the change; reversing the change seemed to mean stopping the change, that is, interrupting the wood burning.

As could be expected there was no difficulty in reasoning that when wood burns a new substance is made.

In the third interview, most pupils managed to identify a temperature difference between the wood and the fire, which disappears as the wood becomes the same temperature as the fire. More difficult, however, was the choice of the abstract picture that depicted what happened to the matter. Two pupils suggested that something is bunching together, but did not defend their choice. On the other hand 'spreading out' was described as happening macroscopically, with either ashes or fire spreading out. Interestingly in this interview 'wood burning' was said to happen by itself.

In the last (D) interview the pupils attempted a microscopic interpretation of 'spreading out' in relation to 'wood burning':

"...the wood turns into ash and like all the little particles in it spread out."

However, even in this interview there existed one pupil who persisted on looking at the change macroscopically:

"I thought you got to bunch things together to make the fire spread out."

The pupils in interview D concluded that the change 'wood burning' could not be easily reversed. The same suggestion, as in the first interview, that a way to reverse wood burning is to put it out by throwing water on to it, this time was ~~was~~ rejected.

"No. Wait, listen. If the wood is already burning, you can't make it back in... - I mean if the wood's turning to ash you can't make it back into wood, can you?"

Appendix 7.8

Comparison of explanations given by the pupils of Group 2 for situations that appear in more than one interview

A7.8.1 Situation 'a hot bath cools down'

This situation appears in the first (A), and the last (D) set of interviews; a similar change was discussed in the study of the topic 'Materials' approximately five months into the intervention and two months before its end.

Common prompts used in the interviews were:

- something spreads out / spreading out
- something bunches together / bunching together
- something disappears or gets used up / disappearing
- substances stay the same / no change

As in Group 1, the situation 'a hot bath cools down' seemed straightforward to the pupils in Group 2 right from the first interview. The pupils were quick to identify the temperature change involved in it. In both the first (A) and fourth (D) interview, no attention was paid to the surroundings and its temperature. As a result the temperature of the system at the end of the change was characterised either on its own using an absolute term, i.e. 'warm' or 'cold', or in relation to its previous state using a relative term, i.e. 'colder'.

In both interviews some pupils thought that something spreads out when a hot bath cools down. In the first one they talked about hot water and steam spreading out and agreed that energy is as well; in the last one they specified only heat as spreading out. Overall, unlike what was found for Group 1, there is no evidence of any substantial progress in pupils' accounts of the situation between the two interviews. However, one has to keep also in mind that by design the last interview asked pupils to look for concentration changes and not for temperature changes, and thus did not provide the relevant prompts for the pupils to develop a more desirable explanation for this thermal change.

A7.8.2 Situation 'ice forming on a pond'

This situation appears in the first (A), and the last (D) set of interviews; a similar change was discussed in the study of the topic 'Materials' approximately five months into the intervention and two months before its end.

Common prompts used in the interviews were:

- something spreads out / spreading out
- something bunches together / bunching together
- something disappears or gets used up / disappearing
- it makes a new substance
- substances stay the same / no change
- it just happens by itself or someone makes it happen it is easy to reverse the change

Just as with Group 1, in the first interview the Group 2 pupils identified correctly the changes of state and temperature occurring to water when ice forms on a pond, and reasoned that these happen spontaneously. Having not had however any formal teaching about the change in question, also similarly to Group 1 pupils, they seemed to move freely between different levels of explanation. They said, for example, that when ice forms something bunches together, but also retained that as it forms it spreads out on to the pond. The second description presupposes looking at the change macroscopically and treating the situation as an event.

In the fourth (last) interview the focus was by design on the concentration change which happens to water as it turns into ice. All the pupils after some discussion

agreed that this change is one of bunching together; amongst them however there were still some who also argued that ice is spreading out over the lake. In other words, the macroscopic overview of the situation was not completely renounced; and neither was their tendency to give contradictory accounts. They reasoned, on the one hand, that water changing into ice makes a new substance, and they maintained on the other that this process is easily reversible because ice *“could melt and become water again”*.

A7.8.3 Situation ‘acid rain eroding a stone statue’

This situation appears in the first (A), and the last (D) set of interviews; no similar change was ever discussed in the classroom.

Common prompts used in the interviews were:

- something spreads out / spreading out
- something bunches together / bunching together
- something disappears or gets used up / disappearing
- substances stay the same / no change

No substantial change was expected in the performance of the pupils in relation to this change in the two interviews, because it deals with a chemical process not met by the Year 7 pupils.

In the first interview all accounts were macroscopic and associative; by this I mean that they were about events related to acid rain in general and not about the processes involved in the erosion of the stone statue. For example, acid rain was seen as a natural phenomenon, *“just coming down”*, and thus it was said to be happening by itself. It was also seen as disappearing when *“it goes into the soil”* or the sun comes up.

In the last interview the pupils again reasoned that it is disappearing, only this time they referred to the statue, which was seen as breaking into pieces. One of the pupils strongly objected the idea that a statue can disappear, but she was outvoted. So, no much progress in pupils’ explanations of the situation, only in the sense that these were more focused and relevant. These results are similar in essence to what was found to be the case for the pupils of Group 1.

A7.8.4 Situation ‘a plant growing’

This situation appears in the first (A), and the last (D) set of interviews; this change was discussed in the study of the topic ‘Life’, which was the last topic to be taught as a part of the intervention.

Common prompts used in the interviews were:

- something spreads out / spreading out
- something bunches together / bunching together
- something disappears or gets used up / disappearing
- it makes a new substance
- substances stay the same / no change
- it just happens by itself or someone makes it happen / it is easy to reverse the change

The accounts the pupils of Group 2 gave for ‘a plant growing’ in the first interview were very similar with those given by the Group 1 pupils. They saw it as an event of transformation where the plant grows from a seed and a new substance is made. However, unlike Group 1, they described this event as mainly happening by itself, i.e. without human intervention, and thus not as easily reversible:

“It can get water from the rain. It would take a long time for the plant to die.”

In terms of concentration changes the pupils described the plant as bunching together and spreading out, both in a macroscopic sense referring to the actions of its leaves.

Unlike the Group 1 pupils however, in the last interview, the Group 2 pupils were split about whether ‘a plant growing’ is spreading out or is bunching together. The

arguments for ‘spreading out’ were very similar to the ones given in the first interview. On the other hand, the pupils who maintained that it is bunching together, seemed to recall what they had learned in the lesson and appealing to the authority of their teacher said:

“Miss X has said that water inside the plant bunches together.”

Furthermore, the pupils held their two different positions so firmly that they used them in the last (‘comparing’) task of the interview to reason for a similarity and a difference respectively between ‘a plant growing’ and ‘your body making extra fat’. Two of them argued that the situations are similar because

“That bunches the food down in your stomach and that bunches the water inside leaves.”

The other two said that the situations are different because:

“[A plant growing] spreads out - the leaves spread out. What’s the point of the leaves just growing on one long branch?”

This time, just as in Group 1, reversing the change was considered as easy as stopping the plant from growing, or letting it die. Especially the former implied human intervention or the absence of it and referred to the event of growing and not to the processes involved in growing.

A7.8.5 Situation ‘a cold drink left out in the sun’

This situation appears in the first (A), and the third (C) set of interviews; a similar change was discussed in the study of the topic ‘Materials’ immediately preceding the third interviews.

Common prompts used in the interviews:

- something spreads out / spreading out
- something bunches together / bunching together
- it makes a new substance
- substances stay the same / no change
- temperature evens out / diff in temp disappears
- temperature stays the same / no change
- it just happens by itself

Similarly to Group 1, in the first interview the change of temperature observed in the drink was attributed to the existence of the surroundings:

“The sun is making the drink warmer.”

In the third interview however, this interaction of the system with its surroundings became explicit and was talked about as being in both directions:

“...the cold drink might be cold and the sun hotter, and then they go to the same temperature after awhile.”

That is, in the later interview the temperature difference between the system and its surroundings was identified and was seen as disappearing after the change.

Also where in the first interview there was talk of “energy of water” spreading out as one pours the cold drink, in the later interview there was more relevant talk about “the hotness in the drink” spreading out when the drink heats up.

As to the spontaneity of the change, only in the later interview did the pupils focus on the relevant process of change and reasoned that it happens by itself.

Finally, as it was expected there was no progress in pupils’ conception of a substance change; in both interviews, though for different reasons, they maintained that a new substance is made when a cold drink is left out in the sun.

A7.8.6 Situation 'warming your hands near the fire / by the radiator'

This situation appears in the second (B), and the third (C) set of interviews; a similar change was discussed in the study of the topic 'Materials' in the interval between the two interviews.

Common prompts used in the interviews were:

- something spreads out / spreading out
- something bunches together / bunching together
- no change (in matter)

In the second interview the pupils of Group 2 ignoring the conventions of the abstract pictures, which focused on concentration changes, reasoned that *"heat is spreading out onto your hands"* when you warm them near the fire. Having said this, two of them correctly asserted at the start that when you warm your hands there is no change, but were eventually persuaded by the 'spreading out' argument.

The same argument, however, did not survive in the later interview; the pupil in charge of the match firmly held this time that there is no (material) change in the hands when they warm up. As to the temperature change involved, as in the case of the other thermal changes discussed before, it was very desirably accounted for by the pupils of Group 2.

A7.8.7 Situation 'wood burning'

This situation appears in the first (A), the third (C) and the fourth-and last (D)-set of interviews; no similar change was ever discussed in the classroom.

Common prompts used in the interviews were:

- something spreads out / spreading out
- something bunches together / bunching together
- it makes a new substance
- something disappears or gets used up / disappearing (A-D)
- substances stay the same / no change
- temperature evens out / diff in temp disappears (A-C)
- temperature stays the same / no change (A-C)
- it just happens by itself or someone makes it happen / it is easy to reverse the change

Concerning the identification of concentration changes, unlike Group 1, there was no evidence of progress for the pupils of Group 2 from the one to the other interview. In the first interview they said that when wood is burning the flames may be bunching together and that carbon dioxide is spreading out, in the third interview they talked of fire spreading out, and finally in the last interview they reasoned that wood is disappearing.

On the other hand there was a noticeable progress in pupils' accounts of the temperature change in the third interview. Despite the fact that, as the Group 1 pupils, these pupils had difficulties both defining the Before and After instances of the change, and identifying its participants (i.e. wood and oxygen), they formulated quite desirable explanations about the possible temperature differences involved in it. Two pupils seemed to maintain that

"When the wood is burning they [the wood and the fire] are the same temperature, and when it is finished burning then the wood goes colder."

and the other two that

"When it starts off they [the wood and the fire] both are at different temperatures [...], but when the wood starts burning, they go to the same temperature."

How the pupils perceived the spontaneity of the process of burning also changed. Whereas in the first interview, they reasoned that someone has to set the process happening and thus it is not spontaneous, in the third interview they thought better:

“People just lit it, maybe, and it burns - and then people are not making it burn - it burns by itself.”

Moreover, seemingly faithful to this view, in the last interview they stated that ‘wood burning’ is not an easily reversible change since “*you can’t get that wood back again*”. Taking into consideration that in the first interview they had asserted that reversing the change amounted to not lighting the fire in the first place, this latter reasoning was clearly an improvement.

Finally, as could be expected, there was a consensus in all three interviews that a new substance is made when wood is burning and that this is ash.

Appendix 7.9

Comparison of explanations given by the pupils of Group 3 for situations that appear in more than one interview

A7.9.1 Situation 'a hot bath cools down'

This situation appears in the first (A), and the last (D) set of interviews; a similar change was discussed in the study of the topic 'Materials' approximately five months into the intervention and two months before its end.

Common prompts used in the interviews were:

- something spreads out / spreading out
- something bunches together / bunching together
- something disappears or gets used up / disappearing
- substances stay the same / no change

As with Group 1 but unlike Group 2, the data from this group suggest that, from the first to the last interview, there was noticeable progress in pupils' accounts of the situation 'a hot bath cools down'. In the first interview, the pupils seemed to struggle to reach a consensus about which of the phrases presented to them applied to the change. Even when they did agree on a given phrase, they found it hard to justify their choice and/or to use the phrase in complete and coherent explanations. There were however three phrases with which the pupils seemed to agree, without much hesitation. One referred to the temperature change involved, which they identified correctly straight away. The other two phrases were: 'something spreads out' and 'a substance changes'. The pupils never explained clearly *what* was thought of as spreading out when a hot bath cools down; what they did say explicitly though is that for them a substance changes when its temperature changes.

In the last interview, the pupils' accounts of the change were considerably more elaborate and coherent. This time, when they explained why they chose to match the situation to the abstract picture of 'spreading out', it was clear that they referred to *steam* spreading out, even though they did not use the word explicitly. One of the pupils in particular, managed a quite sophisticated explanation of the change:

"The hot water is evaporating and then the particles are spreading out."

Moreover, the same pupil, suitably prompted by the interviewer (myself), went on to question whether there is any concentration change happening after all, and whether there is not just a temperature change happening in the situation.

A7.9.2 Situation 'ice forming on a pond'

This situation appears in the first (A), and the last (D) set of interviews; a similar change was discussed in the study of the topic 'Materials' approximately five months into the intervention and two months before its end.

Common prompts used in the interviews were:

- something spreads out / spreading out
- something bunches together bunching together
- something disappears or gets used up disappearing
- it makes a new substance
- substances stay the same no change
- it just happens by itself or someone makes it happen it is easy to reverse the change

Group 3 pupils' performance in the first interview was quite poor. Whereas they did identify the change of state happening to water when ice forms, they limited themselves to stating the temperature of ice in absolute terms, i.e. 'cold', and did not

explicitly identify the relevant temperature change. They also did not identify any concentration change; instead they spoke of ice spreading out onto the pond.

In the last interview the progress was evident, though the pupils still hung on to their macroscopic descriptions for the change. More particularly, the pupils matched the situation to the abstract picture of ‘bunching together’ and said:

“Like it’s forming - it’s bunching to start grow. It’s going to form and grow. Form and grow is the same thing. So it’s going to bunch.”

Moreover, unlike the Group 2 pupils, these pupils acknowledged that no new substance is made when water changes into ice.

A7.9.3 Situation ‘acid rain eroding a stone statue’

This situation appears in the first (A), and the last (D) set of interviews; no similar change was ever discussed in the classroom.

Common prompts used in the interviews were:

- something spreads out / spreading out
- something bunches together / bunching together
- something disappears or gets used up / disappearing
- substances stay the same / no change

No substantial change was expected in the performance of the pupils in relation to this change in the two interviews, because it deals with a chemical process not met by the Year 7 pupils. However, there was a noticeable difference. In the first interview the Group 3 pupils did not manage to choose even one phrase amongst the ones presented to them to describe the change. Yet, in the last interview, they ended up agreeing that it should be matched to the picture of spreading out, because when the statue *“is breaking, it spreads out”* and *“falls all over the place”*.

A7.9.4 Situation ‘a plant growing’

This situation appears in the first (A), and the last (D) set of interviews; this change was discussed in the study of the topic ‘Life’, which was the last topic to be taught as a part of the intervention.

Common prompts used in the interviews were:

- something spreads out / spreading out
- something bunches together / bunching together
- something disappears or gets used up / disappearing
- it makes a new substance
- substances stay the same / no change
- it just happens by itself or someone makes it happen / it is easy to reverse the change

As was the case for the previous situations examined in this analysis, there was a big difference in the accounts the Group 3 pupils gave between the first and the last interview. In the first interview, the accounts were macroscopic, associative and incoherent. To give an example, the pupils said that in a plant growing something disappears, because

“Now you could see the sun and afterwards it disappears.”

In the fourth (last) interview on the other hand the pupils managed to develop a coherent explanation, which is on the lines one would hope for:

“The plant is getting water and it is bunching when it grows.”

Moreover, the pupils explicitly acknowledged that nothing spreads out in this change, and seemed inclined to think that it is an easily reversible change.

A7.9.5 Situation 'a cold drink left out in the sun'

This situation appears in the first (A), and the third (C) set of interviews; a similar change was discussed in the study of the topic 'Materials' immediately preceding the third interviews.

Common prompts used in the interviews:

- something spreads out / spreading out
- something bunches together / bunching together
- it makes a new substance
- substances stay the same no change
- temperature evens out / diff in temp disappears
- temperature stays the same / no change
- it just happens by itself

Similarly to Groups 1 and 2, in the first interview the change of temperature observed in the drink was attributed to the existence of the surroundings:

"The sun is making the drink warmer."

In the third interview, this idea seemed to persist, but differently from before the pupils compared the temperatures of the cold drink and of the sun in the 'before' and 'after' instances arguing that the observed temperature difference would eventually disappear. Only one child failed to do this.

In the first interview the pupils also said that something spreads out in the given situation, but did not manage to explain this coherently. Interestingly in the third interview the pupils started from reasoning that the drink might spread out *after* it gets hot and ended up concluding that it should be bunching together *while* it is getting hot. Of course *what* is bunching together as the drink gets hotter is its energy and not its matter; the pupils could not yet appreciate this idea but one could see how a teacher could use their intuitive reasoning as an introduction to it.

Finally, regarding the spontaneity of the change, only in the later interview did the pupils focus on the relevant process of change and reasoned that it happens by itself. However, in the same interview they also maintained wrongly that as the cold drink warms up a new substance is made. Very similar results are reported in the corresponding analysis of Group 2.

A7.9.6 Situation 'warming your hands near the fire / by the radiator'

This situation appears in the second (B), and the third (C) set of interviews; a similar change was discussed in the study of the topic 'Materials' in the interval between the two interviews.

Common prompts used in the interviews were:

- something spreads out / spreading out
- something bunches together / bunching together
- no change (in matter)

In the second interview the pupils came up with three different suggestions for which picture the situation 'warming your hands near the fire' should be matched to. The two were only relevant by association to the given change; they were concerned with the event of burning and the presence of wood and fire in the schematic picture which depicted the situation (see also Group 1). The third suggestion, which also prevailed, was the intended one by the task and recognised explicitly that there was no concentration change involved in the situation; the sole pertinent change was one of temperature.

A similar suggestion, however, did not prevail in the third interview, where the pupils preferred instead to match the situation to the picture showing a substance 'spreading out', arguing that heat from the radiator spreads out on the hands. In the same interview, similarly to Groups 1 and 2, the pupils accounted for the relevant temperature change in a very desirable way.

A7.9.7 Situation ‘wood burning’

This situation appears in the first (A), the third (C) and the fourth-and last (D)-set of interviews; no similar change was ever discussed in the classroom.

Common prompts used in the interviews were:

- something spreads out / spreading out
- something bunches together / bunching together
- it makes a new substance
- something disappears or gets used up / disappearing (A-D)
- substances stay the same / no change
- temperature evens out / diff in temp disappears (A-C)
- temperature stays the same / no change (A-C)
- it just happens by itself or someone makes it happen / it is easy to reverse the change

Concerning the identification of concentration changes, similarly to Group 1 and unlike Group 2, there was some evidence of some little progress between the first and the last interview. In the first and third interview the pupils talked of fire spreading out and of wood disappearing. In the fourth interview one pupil seemed to differentiate him/herself from such accounts by claiming that it is not (just) fire which is spreading out when wood is burning, but also wood itself because:

“The wood when it’s burning it goes everywhere..., it doesn’t stay wood, it doesn’t stay sticks of wood anymore.”

Although still not a fully desirable explanation, this quote shows in my opinion that the pupil was on the way to developing one.

Moreover, concerning the account of the temperature change involved in ‘wood burning’, the pupils of Group 3 treated wood and fire as system and surroundings respectively and reasoned that they would end up at the same temperature. A similar account was also met in the corresponding analyses for Groups 1 and 2.

Moreover, similarly to what was the case for these other groups in the third interview, the pupils of Group 3 reasoned that the wood burns ‘by itself’ after it has been started off.

Appendix 9.1

Matches Made in the 'Grouping' Task of the Year 8 First (A) Interviews - Per Group of Pupils

Year 8A Situations	A1	A2	A3	A4	A5
1 scent or after-shave evaporating from the skin	↑	↑↑	↑	↑	↑
2 ice forming on a pond	↑↑	↑↑	↑	↑↑	↑↑
3 a cold drink left out in the sun	↑	↑	↑	↓	↑
4 acid rain eroding a stone statue	↓	↓	↑	↑	↑
5 hot lava from a volcano turns solid	↑	↑	↓	↑↑	↓
6 making soup out of powder soup and water	↑	↑	↑	↓	↓
7 fruit drying in the sun	↓	↑	↓	↑	↓
8 a plant growing	↓	↑	↑	↓	↑
9 a car windscreen being shattered	↓	↓	↓	↓	↓
10 wood burning	↓	↓	↓	↓	↓
11 digesting food	↓	↓	↓	↓	↓
12 a hot bath cools down	↓	↓	↓	↓	↓

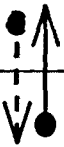













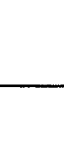

















Appendix 9.2

Matches Made in the 'Grouping' Task of the Year 8 First (A) Interviews - Per Situation

Situations used in the first (A) Y8 interviews	1 scent or after-shave evaporating from the skin	2 ice forming on a pond	3 a cold drink left out in the sun	4 acid rain eroding a stone statue	5 hot lava from a volcano turns solid	6 making soup out of powder soup and water	7 fruit drying in the sun	8 a plant growing	9 a car windscreen being shattered	10 wood burning	11 digesting food	12 a hot bath cools down
1 scent or after-shave evaporating from the skin	•		A4 A5	A2			A3 A5				A1	
2 ice forming on a pond		•		A1	A3							A2 A4 A5
3 a cold drink left out in the sun	A2		•				A1 A3 A5					
4 acid rain eroding a stone statue				•		A5					A3 A4	
5 hot lava from a volcano turns solid		A3 A5			•					A1 A4	A2	A1
6 making soup out of powder soup and water					A4	•					A1	A2 A3
7 fruit drying in the sun			A1 A3				•	A4		A2 A4		
8 a plant growing							A1	•		A3 A5	A2	
9 a car windscreen being shattered		A1 A4	A2	A3	A5				•			
10 wood burning					A1 A3 A5		A2			•		
11 digesting food			A1	A3		A1	A5				•	
12 a hot bath cools down		A1 A3		A1	A5		•					O

Appendix 9.3

Matches Made in the 'Grouping' Task of the Year 8 Last (D) Interviews - Per Group of Pupils

Year 8D Situations	D1	D2	D3	D4
1 a plant growing				
2 running and using up food				
3 ice forming on a pond				
4 sweating to stay cool				
5 wood burning				
6 acid rain eroding a stone statue				
7 your body making extra fat				
8 a hot bath cools down				

Appendix 9.4

Matches Made in the 'Grouping' Task of the Year 8 Last (D) Interviews - Per Situation

Situations used in the last (D) Y8 interview	1 a plant growing	2 running and using up food	3 ice forming on a pond	4 charging a car battery	5 wood burning	6 acid rain eroding a stone statue	7 pulling a catapult to get ready to fire a stone	8 a hot bath cools down
1 a plant growing	•	D1?	D2 D3 D4	D3	D3			
2 running and using up food	D1	•			D2 D3 D4			
3 ice forming on a pond	D3		•					D1 D3 D4
4 charging a car battery				•			D1 D2 D3 D4	
5 wood burning					•	D1 D2 D3 D4		D1
6 acid rain eroding a stone statue				D3		•		D2
7 pulling a catapult to get ready to fire a stone		D4		D1			•	
8 a hot bath cools down			D2					•

*D1? could not decide

Appendix 9.5

‘Matching’ and ‘Comparing’ Tasks: Comparison Across Year 8 Group 2 Interviews

A9.5.1 Chemical change: Matter ‘joining’ and ‘splitting’

A9.5.1.1 ‘A substance changes’ - ‘It makes a new substance’

The phrase ‘a substance changes’ was not chosen as a match for any of the situations in the first interview. On the other hand, the phrase ‘it makes a new substance’ was discussed in relation to four out of the six situations presented to them. (This group of pupils had time to discuss only the first three pairs out of the four pairs of situations used with the other groups.) Similarly to the first group the pupils of this group thought that this phrase applied to situations in which as a result of the change a ‘different’ (in some aspect and not necessarily different in substance) object appeared. So they thought it true for the situation ‘ice forming on a pond’ *“because it was water before and now it is ice”*, even though they acknowledged a couple of minutes afterwards that *“ice is water, it’s just hard; it’s just solid that’s all”*. In the same way a new substance was seen as being made when hot lava from a volcano turns solid and when wood burns into ashes. Unlike the first group, ‘a plant growing’ was not seen as making a new substance; there was no apparent ‘new’ object in this case. The criteria for deciding whether a new substance is made during a change became more sophisticated in the third interview. Thinking about whether an explosion produces new substances in the ‘comparing’ (third) task of the interview a pupil said:

“No, I wouldn’t have thought so. But the metal on that [the car sketched in the picture of the situation as exploding] could change, yes the colour changes.”

It has been discussed elsewhere (section 8.4) how a colour change was one of the criteria pupils employed to differentiate between physical and chemical changes.

A9.5.1.2 ‘Joining’ - ‘Splitting’ - ‘Re-arranging’

In the second interview, three months later, the abstract picture of ‘joining’ was chosen as a match for five out of the eight situations by one or more pupils; it was finally kept as a match for three of them ‘a car rusting’, ‘extracting copper by electrolysis copper sulphate solution’ and ‘a baby’s bones growing’. It is interesting that the discussion of the appropriateness of its match to the change ‘a snowman melting’ echoed the discussion the first group of pupils had about whether ‘a snowman melting’ is a ‘splitting’ change. The same idea, namely that ice is something more than water, or in other words that water joins with something (oxygen was a tentative suggestion by one of the pupils of this second group) to make ice, was offered as a justification of the claims in both cases. This time however, the counter argument that water and ice are one and the same substance was stronger and survived. Furthermore, the account given by this group for ‘car rusting’ - a situation previously studied - was very desirable; unlike the first group they identified the two reactant substances, iron and oxygen, and they explicitly acknowledged that the product rust is a new substance. Lack of knowledge about the reactant substances and the processes involved forbade them to formulate similar descriptions for the change ‘a baby’s bones growing’. As for the situation ‘extracting copper by electrolysis a copper sulphate solution’, a situation also previously studied, the pupils’ explanations suggest that they had mistaken the change of colour observed on the carbon electrodes due to the copper deposit to be a ‘joining’ change. And accordingly they attempted to name the participant substances:

"The blue stuff, copper sulphate, and electronic or something I think, join together and make a new substance, copper, copper colour."

As alternative to 'joining' the pupils also considered the 're-arranging' picture. They seemed to recall that in the classroom they had used copper oxide to produce copper sulphate:

P1: *"It could be, because you know that blue thing, may be that blue liquid had a different kind of acid in it and..."*

P2: *"It did have copper oxide, copper oxide acid [...] sulphur, I think..."*

P1: *"And that one was another substance and then the other one joined to this one and the other one was..., and then they became two different substances. Yeah, I agree with re-arranging."*

The last quotation shows that, although the pupil found it hard to name the four substances depicted in the abstract picture, she understood the conventions and what they showed. The picture of 're-arranging' was also chosen by one other pupil for 'a snowman melting', 'a baby's bones growing' and 'metal foil being crumpled up'; this time the notion of 're-arranging' was not used in the intended way but in an everyday sense.

The situation 'extracting copper by electrolysis a copper sulphate solution' was originally intended to be matched to the abstract picture showing 'splitting'. This picture was not discussed by this group at all. It was matched to three (other) situations by one pupil each time (the same one in two cases), but the choices were not defended.

A9.5.2 No change: Matter 'staying the same'

The use of the phrase 'substances stay the same' by the pupils in the first interview was consistent with observations made above as well as in the analysis of the first group interviews. Similarly to the other pupils, they explicitly denied that substances stay the same in 'a cold drink left out in the sun' and in 'a hot bath cools down' since in both cases the system was seen as undergoing a temperature change. However, in the second interview the pupils were happy to match the 'no change' picture to 'a snowman melting' and to 'metal foil being crumpled up', having first acknowledged that in both cases no new substance is made and nothing gets mixed (options covered by the other abstract pictures). 'No change' is also the picture chosen (among these of 'spreading out' and 'bunching together') and kept in the third interview for the changes 'an electric iron cools down after being switched off', 'smoke filling the air over a city', 'warming your hands by the radiator' and 'your body staying warm on a cold day'. It was originally also matched to the changes 'melting wax' and 'your body making extra fat'. In almost all the justifications given for the matches it was clear that by 'no change' the pupils meant 'no change of substance' in the intended chemical way, allowing thus for changes in size, shape and temperature.

A9.5.3 Physical change: Matter 'mixing' and 'un-mixing'

The phrase 'something is mixing' was (again similarly to the first group) applied generously and with its everyday sense in the first interview; heat was thus thought of as 'mixing' with a cold drink making it warm when this is left out in the sun, fire as 'mixing' with wood in 'wood burning', and sunlight as 'mixing' with a plant so that it grows.

In the second interview the use of 'mixing' appears more sophisticated and desirable. In 'purifying water' for example, although the names of the substances may not have been again known to the pupils, they preferred to talk about "solid and liquid" first mixing and then separating, that is they preferred to name the participants at a

generic level, than at a particular object level. They also used the term 'mixing' to explain what they thought as dissolving in the change 'putting Alka Seltzer in water'. As for the abstract picture of 'unmixing', this was matched appropriately to the situations 'cleaning a paint brush in water' and 'purifying water'.

A9.5.4 Temperature differences and energy flows

A9.5.4.1 'Energy spreads out' - 'Energy becomes concentrated (in something)'

About the use of the term 'energy' and consequently of the expressions 'energy spreads out' and 'energy becomes concentrated in something' observations similar to those for the first group were made. That is, in the first interview energy was seen as making things happen and its change of concentration was mostly related to a spatial change of concentration of the object said to contain it. First of all the pupils avoided selecting any of these expressions to describe the changes presented to them, it was only after the interviewer prompted their use that they attempted it. And then they seemed to be very unsure about whether and how energy was involved in the changes. So, energy was said not to play any role in 'a hot bath cools down', whereas there *"might be"* some in 'a cold drink left out in the sun'. Moreover, energy might be *"getting stronger"* and spreading out as a plant grows and gets bigger, and might be *"getting hotter"* as wood burns. The one thing they seemed definite about is that *"energy is making the plant grow more"* and thus it also 'becomes more concentrated'.

In the third interview, four months later, the progress was evident. Although still associated sometimes with material changes in concentration, now energy was seen as flowing and almost always as accompanying temperature changes.

'Energy spreads out'

The picture 'energy spreads out' was chosen for six out of the eight situations; it was finally kept as a match for four of them, namely for 'an electric iron cools down after being switched off', for 'melting wax', for 'smoke filling the air over a city' and for 'an explosion'. In all four cases, the idea was appropriately applied. Interestingly the discussion of the situation 'an electric iron cools down after being switched off' revolved around the 'substantial' nature of heat. Three out of the four pupils had matched the situation to both the picture showing energy spreading out due to temperature differences, and to this showing particles spreading out. For them, the second picture represented *"the warm substance"* which spreads out. The fourth pupil however, pointed out and seemed to win the argument that *"heat is the energy, not the substance"*. The same issue was raised when the situation 'warming your hands by the radiator' was discussed. As mentioned before in almost all the cases the spreading out of energy was seen as accompanying a temperature change in the system; the existence and absence of a temperature difference between the system and its surroundings were often explicitly identified in the 'before' and 'after' instances of the changes respectively. Finally, in the 'comparing' task of this interview the changes 'smoke filling the air over a city' and 'an explosion' were found similar because:

"They both give out energy and become the same temperature as the surrounding."

'Energy becomes concentrated'

The use of the picture 'energy becomes concentrated' evolved on similar lines. The picture was matched originally to four changes by one or more pupils, it was finally kept as a match for the changes 'water vapour forms clouds and it rains' and 'your body making extra fat', whereas it was also thought a possible match for the change 'warming your hands by the radiator'. In the first case, the pupils felt compelled to

choose this picture since they identified the necessity of an inwards flow of energy for vapour to 'bunch together'. They, however, could not come up (at the start at least) in their accounts of the situation with any of the temperature changes also depicted in the pictures. In the following extract, it becomes obvious how in order to attempt to satisfy these conventions the pupils distorted their explanation of what is happening when water vapour forms clouds and it rains:

P1: *"But something gives the energy to get together - isn't it - something gives the energy. It doesn't get warmer, it stays the same temperature, but something gives the energy gives to the cloud to get together."*

[...]

P1: *"Maybe the cloud is cooler than the surroundings and..."*

P2: *"Yeah... and something is giving the energy and making..."*

P1: *"...the surroundings giving the energy to make it to get together..."*

P2: *"Yes, and then makes it hot. Something like that."*

Despite the facts that neither was the above match the intended one, and that nor did the explanation which the pupils arrived at succeed in justifying it appropriately, I find that the above dialogue contains ideas which are essential for the project and not so straightforward. The pupils rather instinctively maintained that a 'bunching together' process needs to be driven and with the aid of the pictures seemed to make the implicit acknowledgement (expressed explicitly rather clumsily) that the driving process should involve somehow a destruction of a temperature difference.

A similar situation arose in the discussion of the change 'your body making extra fat'. Only now the discussion was more complicated and less conclusive since food was seen as giving energy to the body, but the body as remaining at a temperature difference from its surroundings.

A9.5.4.2 'Energy escapes I' - 'Energy is stored I'

Finally, in the fourth interview, a month after the third one, the same pictures (now with labels 'energy escapes I' and 'energy is stored I') were almost always talked about in terms of energy flowing in the system or out of it, causing its temperature to change. Moreover, in many cases a match was contested because the temperature change depicted by the picture, or the temperature difference, did not apply to the situation matched to it. Similarly to the first group results, in this interview compared with the previous one there was less mention of the temperature of the surroundings.

The picture 'energy escapes I' was originally chosen for all eight situations by one or more pupils; it was finally kept for 'ice forming on a pond', 'acid rain eroding a stone statue' and 'a hot bath cools down'. Interestingly, in all three cases the system seen as giving out energy was said explicitly or implicitly to remain with no energy in the 'after' instance. In 'ice forming on a pond' *"the water was a bit warm and it gives out all the energy it has and cools down"*; in 'acid rain eroding a stone statue' acid rain *"gives out energy to the stone and destroys it and then it doesn't have any"*; and in 'a hot bath cools down' *"the water is hot..., and the energy goes out and it cools down"*. This idea is consistent with a view of energy as a localised entity, also identified elsewhere.

As for the picture 'energy is stored I', it was kept as a match only for the situation 'running and using up food'. This was because 'using up food' was understood as 'eating food', and energy was identified as flowing from the food to the human body, keeping it thus at a warmer temperature than its surroundings. This match was inappropriate, although one can see how the explanation given complied with the conventions of the picture chosen. The picture was also chosen by three out of the four pupils for the change 'wood burning'; fire was seen as providing energy to the wood and as creating a temperature difference between the wood and its

surroundings. However, the observed outward (from the wood) flow of energy was eventually thought of as more important, and the picture was eventually abandoned in favour of the 'energy escapes II' picture.

A9.5.5 Stores of concentrated energy and energy flows

'Energy escapes II' - 'Energy is stored II'

This group overall made better use of the pictures 'energy escapes II' and 'energy is stored II' than the first group. They seemed to better comprehend both the conventions and the ideas behind them.

Even when they did not agree on the most appropriate match some of the explanations they attempted in order to support their arguments were quite sophisticated. For example, although the change 'running and using up food' was, as mentioned in the above section, eventually kept as a match to the 'energy is stored I' picture, one pupil maintained that the picture 'energy escapes II' represents the change better because

"The energy goes out... and he runs and the particles join again."

or expressed in other words at a later stage in the interview:

"When you run the particles force themselves to get together and the energy goes out."

Clearly here the pupil helped by the abstract picture attempts to combine the idea of an outward energy flow with that of a 'joining' chemical reaction.

In the case of 'wood burning' a similar suggestion that oxygen and wood join together and energy spreads out, which originated with some prompting from the interviewer (see section above), was more readily accepted. Moreover, on this basis in the 'comparing' task of the interview the pupils reasoned that the two situations 'running and using up food' and 'wood burning' are similar because *"they give out energy"*.

The same picture ('energy escapes II') was chosen as a match for the situation 'acid rain eroding a stone statue' by two pupils who attempted to explain the erosion of the stone statue in terms of the particles *"getting back together"*. However, lack of knowledge about the chemical change involved weakened their explanation, which appeared quite clumsy, so that they abandoned it in favour of the problematic but more straightforward match of the 'energy escapes I' picture.

The use of the picture 'energy is stored II' was always appropriate and generated very stimulating and interesting discussions, particularly in conjunction with the situations 'a plant growing' and 'charging a car battery'. In the case of 'a plant growing', and starting from the assertion that a plant needs energy to grow, thus there is a flow of energy into the system, the pupils' reasoning evolved as following:

"We are storing energy in the plant by making it bigger, but it doesn't get warm. ... Maybe by splitting the particles it's making it grow bigger. ... In picture No 5 ['energy is stored II'] first the particles are together and then the energy goes in and splits the particles into parts and it stores itself in the particles, between it. ... But what could be the particles? ... It's not cells, is it - the particles?"

Despite their lack of knowledge about the participants and processes of the change, which prevented them from arriving at a more accurate and precise explanation, with the aid of the abstract pictures the pupils managed to formulate a quite sophisticated explanation at a high level of abstraction. Indeed, in their account of the situation 'charging a car battery' the pupils themselves could not have put it in better words:

"It doesn't matter what sort of particles, it is the energy goes in the particles and splits them up to store itself. ... It's like that plant growing..."

Finally, similarly to group one interview, almost always a choice of the 'energy escapes II' picture was combined with the choice of the 'it just happens by itself' picture and equivalently the choice of the 'energy is stored II' picture was combined with the choice of the 'it needs something to make it happen' picture. This is a very welcomed result from the project's point of view.

A9.5.6 Steady-state systems:

'No energy change' - 'Energy stays concentrated'

In the third interview the picture 'no energy change' was originally chosen in relation to three situations by one or more pupils. For none of them was it an appropriate match and the group did not finally retain any of these matches. Moreover, the pupils who made them in the first place did not care to justify them or when they did their justifications were very unclear. Only in one case, could it be maintained that by the choice of this picture the pupil implied the absence of a temperature difference or a temperature change in the given situation. *"The water is cold and the rain is cold"*, she said for the situation 'water vapour forms clouds and it rains'.

In the fourth interview, the same picture was chosen by one or more pupils as a match to five changes. As before, none of these matches was the intended one by design or was retained by the group, but this time some of the justifications offered by the children clearly related the choice of this picture to either an absence of temperature difference between the perceived system and its surroundings, or to an absence of temperature change in the system. The girl quoted above for example, in this interview justified her choice of abstract picture for the situation 'a plant growing' as follows:

"Because there's no energy change, and it's not warmer than the surroundings and it's not colder than the surroundings..."

The use of the picture 'energy stays concentrated' in the third interview was more desirable than the use of the 'no energy change' picture. It was originally chosen for the situations 'smoke filling the air over a city', 'your body making extra fat' and 'your body staying warm on a cold day', and it was discussed as a possible match for the change 'warming your hands by the radiator'. Although by design it was intended mainly as a match for the situation 'your body staying warm on a cold day', a match made and retained by the group, and as a possible one for the situation 'your body making extra fat', for all suggested matches the justifications offered by the pupils attempted (with various success) to make use of the ideas depicted by the abstract picture. Most of the explanations, for example, explicitly acknowledged the existence and sustenance of a temperature difference between the relevant system and its surroundings. Most of them also attempted to relate this maintenance of temperature difference to some sort of an in-flow and an out-flow of energy (or matter in some cases) in the perceived system. An example of an acceptable account, which was produced in relation to an incorrect match, is given by the following quotation, in which a pupil explains why the abstract picture 'energy stays concentrated' could be an appropriate match to the change 'warming your hands by the radiator':

"It could be that one as well, [...], like the radiator gets warmer by switching it on and it spreads energy, but... it stays the same..., it gets and it gives out."

A9.5.7 Spontaneous and non-spontaneous change

A9.5.7.1 *'It (just) happens by itself' - 'Someone makes it happen' - 'It needs something to make it happen'*

Concerning the use of the above expressions and respective abstract pictures (where these existed), similar issues with those discussed in the analysis of Group 1 interviews arose.

The perceived presence (or absence) of an agent, most often identified as a human action, which sets the change going or which creates the circumstances for it to happen, was the key criterion for whether the pupils reasoned that a change 'happens by itself' or not, in the first interview. Comparing to Group 1 pupils' responses, these (Group 2) pupils allowed for more changes to 'happen by themselves', but still based on the same criterion. In the case of 'a plant growing' for example, the arguments against and for considering the change as 'happening by itself' were respectively: "*People put it in the sun...*" and "*But still... people don't pull it out to grow*".

The same kind of reasoning was also present during the fourth interview. The picture 'it just happens by itself' was originally chosen by one or more pupils as a match for six situations and was considered as one also for the remaining two; however, it was finally kept only for 'wood burning' and 'a hot bath cools down'. In addition to these two situations, by design it was also intended to be matched to the situations 'running and using up food', 'acid rain eroding a stone statue', and 'ice forming on a pond' (seen as a cooling down process). So, it seems that whereas the pupils were happy to discuss the possibility of a change to be 'happening by itself' they were still quite reluctant to assert that this was the case. Even for the two situations that they did so, only for 'a hot bath cools down' it appeared a quite straightforward decision; for the match of 'wood burning' I (the interviewer) had to prompt them to think about how the change evolves after it is started off, in order to help them conclude that it 'just happens by itself'.

In accordance with this observation, the abstract picture 'it needs something to make it happen' was selected by at least one pupil as a match to every one of the eight situations presented to them, and was finally retained for six of them, that is, for all it was intended (i.e. for 'a plant growing', 'charging a car battery' and 'pulling a catapult to get ready to fire a stone'), plus another three intended by design to be thought of as spontaneous changes. In none of these cases was it explicitly acknowledged that another spontaneous change needs to happen to drive these changes.

However, the arguments the pupils came up with to explain their choices seemed overall more sophisticated and extended than in the first interview. There seemed to be less tendency to attribute the agency of each change discussed to a human action. The justification for example for why the 'plant growing' 'does not just happen by itself' this time talked about the need for the plant to have sunlight and water, and not about the need for a person to put it in the sun, as suggested before. Moreover, in the case of 'ice forming on a pond' the identification of the necessary condition of the weather to be 'cold' for the change to happen, led the pupils very close to expressing the idea that it is the spontaneous process of cooling down of the water which drives its change of phase from water to ice.

A9.5.7.2 *'It is easy to reverse the change'*

Similar observations to the ones made in the analysis of Group 1 interviews were also made here concerning the application of the phrase 'it is easy to reverse the change' and the meanings the pupils seemed to attribute to it. In other words, the pupils could on the whole identify correctly the reverse processes in the case of

physical processes and specially in the case of thermal changes. On the other hand, in case of more complicated changes they often resorted in suggesting the repetition and/or the cessation of the change as a way of 'reversing' it, or they came up with ideas of other changes/actions which could obliterate the consequences, results or products of the first ones. They rarely reasoned about the 'easiness' of the reverse process and when they did they rarely talked about it in the sense intended; they rather interpreted easy to mean feasible or natural.

Appendix 9.6

‘Matching’ and ‘Comparing’ Tasks: Comparison Across Year 8 Group 3 Interviews

A9.6.1 Chemical change: Matter ‘joining’ and ‘splitting’

A9.6.1.1 ‘A substance changes’ - ‘It makes a new substance’

Similarly to the first group of pupils and unlike the second group, the pupils of the third group used the phrase ‘a substance changes’ quite widely in the first interview. They said that it describes what is happening in five situations (‘a cold drink left out in the sun’, ‘a hot bath cools down’, ‘ice forming on a pond’, ‘hot lava from a volcano turns solid’ and ‘making soup out of powder soup and water’), and questioned whether it is also true for the situation ‘acid rain eroding a stone statue’. A change of temperature, of state, or of object identified in concrete terms seemed to count in their view as criteria for whether a substance changes. In the case of ‘acid rain eroding a stone statue’ the pupils had difficulties identifying what is the ‘new’ object in concrete terms that is being produced. Moreover, with the exception of the two purely thermal changes (‘a cold drink left out in the sun’ and ‘a hot bath cools down’) all the above changes, as well as the changes ‘wood burning’ and ‘a plant growing’ were considered as ‘making a new substance’. The ‘acid rain eroding a stone statue’ was once more and for the same reasons thought of as not making a new substance: *“the acid rain is not making anything there”*. Also, there was a small hesitation whether the change of state of water to ice should be thought of as a process which makes ‘a new substance’ or not.

In the third interview the progress in the use of the expression of the phrase ‘it makes a new substance’ was small. Now some pupils recognised that a change of temperature is not necessarily followed by a change of substance and that there is no new substance made in the situation ‘water vapour forms clouds and it rains’, but in both cases only after I, as the interviewer, challenged them explicitly to think in these terms.

A9.6.1.2 ‘Joining’ - ‘Splitting’ - ‘Re-arranging’

Concerning the use of the abstract pictures showing ‘joining’, ‘splitting’ and ‘re-arranging’ in the second interview, it appeared remarkably similar, in the kind of issues it gave rise to, to the use made of them by previous groups. The picture ‘joining’ was chosen by one or more pupils as a match for the situations ‘a car rusting’, ‘a baby’s bones growing’ and ‘putting Alka Seltzer in water’. It was finally kept for the two first ones and also for the change ‘extracting copper by electrolysis copper sulphate solution’. This last match arose from the discussion the children had about their original choices, which were the pictures ‘splitting’ and ‘mixing’. What the pupils remembered from the experiment they had done in the corresponding lesson was the deposit of copper on the carbon rods. They therefore reasoned that *“copper is joining into that carbon rod”*. In particular, the fact that the carbon rod changes colour in the process seemed to determine for them that ‘joining’ takes place.

The picture ‘splitting’ on the other hand was finally kept for the changes ‘a snowman melting’ and ‘cleaning a paint brush in water’. For neither was it an appropriate choice. Interestingly the first match was made (though not necessarily retained) by both other groups for similar reasons (see sections 9.3.1.2 and A9.5.1.2); in all cases it was contested and discussed heatedly. Despite the fact that the picture of ‘splitting’ was matched in the end inappropriately, there is some evidence that the pupils had

some understanding of the difference between ‘splitting’ and ‘unmixing’ (see discussion of ‘purifying water’ below).

Finally, the picture ‘re-arranging’ was chosen by only one pupil in relation to the change ‘a baby’s bones growing’. From the explanation he gave for his choice, there is no indication that he paid any attention to the conventions of the abstract picture.

Almost all the justifications that the pupils gave for the above choices attempted to account for the changes macroscopically. In other words, they mostly talked about objects ‘joining’ and ‘splitting’, they rarely identified the relevant substances, and they never made any references to particles reacting. Obviously, the knowledge they had of the process under consideration made a difference to how they described it. For example, the account of the situation ‘a car rusting’ (i.e. *“metal is joining with the air and it’s rusting”*), about which the pupils knew more from their lessons and everyday experience, was more desirable, even if only marginally, than the account they gave of ‘putting Alka Seltzer in water’ (i.e. *“The medicine one [is] joining with the water.”*).

Another thing I observed was that the explanations given for the ‘joining’ matches were more elaborate on the whole than the ones given for the ‘splitting’ matches. Most of the time the reasoning behind these latter matches consisted of little more than debating whether the substance under consideration has been the product of a ‘joining’ process in the first place. So, for example, in order for the pupils to decide whether ‘purifying water’ is a ‘splitting’ change or an ‘unmixing’ one they argued whether the impurities, identified as ‘rock salt’ by them, should be thought of as ‘joined’ with the water or not:

P1: *“When you mix/dissolve salt with water it becomes joined together, isn’t it? They dissolve. So you can split it.”*

P2: *“No, [it is unmixing] because it ain’t joining - I don’t think it’s joining. If it was joining, then the rock would go with the..., the rock would be dissolved with water and everything would go under the thingy - under the funnel, or whatever it’s in there.”*

Having said this, the above exchange, which shows among other things pupils using a sound principle to differentiate between the ‘unmixing’ and the ‘splitting’ process, would have been very welcomed by the project, if pupils had not used the terms ‘dissolve’ and ‘join’ as synonyms in it. In other parts of the analysis (see pupil case studies) I have already discussed extensively the difficulties the pupils had in discerning correctly the process of ‘dissolving’.

A9.6.2 No change: Matter ‘staying the same’

The use of the phrase ‘substances stay the same’ in the first interview was consistent with the use of the phrases ‘a substance changes’ and ‘it makes a new substance’ discussed in the previous section. The pupils did not match the phrase to any of the changes presented to them and explicitly found it untrue in the case of the situations ‘a cold drink left out in the sun’, ‘a hot bath cools down’, ‘ice forming on a pond’ and ‘hot lava from a volcano turns solid’. A small shift can be observed in how they perceived the same idea in the second interview. The equivalent ‘no change’ picture was kept as a match to the change ‘metal foil being crumpled up’, but was also suggested as a possible match for the changes ‘a snowman melting’ (by one pupil) and ‘a baby’s bones growing’ (by two pupils). In the first case it was explicitly said that there is no change of substance, but merely one of shape; in the second case the picture was selected indirectly as the only possible match after excluding the others; and in the third case ‘no change’ meant no ‘new’ substance in macroscopic terms (*“same substance is joining the same substance”*).

A9.6.3 Physical change: Matter ‘mixing’ and ‘un-mixing’

A small shift is perceived in the second interview in the use of ‘mixing’ and ‘unmixing’. In the first interview the term ‘mixing’ was used in an everyday sense and indiscriminately for physical and chemical changes, whereas the term ‘unmixing’ was not used at all. In the second interview, although the pupils still employed the terms in a macroscopic sense, they also made clear attempts to use some of the appropriate relevant concepts in their explanations. For example, we saw above how they debated the match of ‘purifying water’ to the ‘unmixing’ picture. The choice of the picture ‘mixing’ for the change ‘putting Alka Seltzer in water’ was also justified as follows:

“When you put a tablet into water it dissolves, so it is mixing.”

To conclude, whereas there were several indications that by the end of the second interview the pupils could read correctly the abstract pictures depicting physical and chemical change and that they had become conscious of the need to differentiate their use, there was little evidence that they could do this consistently or that they could always use the relevant terms in the intended way when they accounted for change.

A9.6.4 Temperature differences and energy flows

A9.6.4.1 ‘Energy spreads out’ - ‘Energy becomes concentrated (in something)’

The issues concerning the use of these phrases and pictures by the pupils of the third group are on the same lines as with the previous two groups.

From the first to the third interview, i.e. four months later, there is a significant change in how the pupils made use of the ideas ‘energy spreads out’ and ‘energy becomes concentrated’. In the first interview these ideas (in the form of phrases) were hardly used, and when they were used, they were used with a lot of hesitation and were not seen as exclusive choices. So, for example, the children agreed that energy is spreading out in a hot bath which cools down, but also debated (inconclusively) whether energy is spreading out in the case of a cold drink left in the sun. They saw ‘wood burning’ as *“making energy”* -because *“the more heat [...] the more energy is up”*- and reasoned that energy becomes concentrated in it, but also agreed that ‘energy spreads out’ from it since *“the flames would spread out, that means energy from the flames would spread out also”*. Furthermore, to neither of the changes ‘ice forming on a pond’ or ‘hot lava from a volcano turns solid’ did the pupils match any of these two phrases.

In the third interview, the corresponding abstract pictures were used much more desirably. The picture ‘energy spreads out’ was kept as a match to the changes ‘an electric iron cools down after being switched off’, ‘melting wax’, ‘smoke filling the air over a city’ and ‘an explosion’. The picture ‘energy becomes more concentrated’ on the other hand, was kept as a match to ‘your body making extra fat’ and ‘warming your hands by the radiator’, and was discussed (without arriving at any decision) as a possible match for the change ‘your body staying warm on a cold day’.

But more importantly, the explanations the pupils gave for these matches were overall much more elaborate and sophisticated than previously. Although still associated sometimes with concentration changes of matter, most often energy was seen as flowing out of or into the systems considered causing their temperatures to change. Moreover, in discussions of the simpler thermal changes such as ‘an electric iron cools down after being switched off’ pupils tended to identify both the temperatures of the system and its surroundings, often in relative terms, and acknowledge that they ended up the same.

On the other hand, pupils tended to pay less attention to the conventions of the abstract pictures and fall back on treating energy as one with matter when they discussed the more complicated changes, such as ‘an explosion’ or ‘your body making extra fat’. Whereas the changes themselves were familiar to the pupils, the processes involved in the changes were often unknown to them, and thus their accounts seemed rather superficial, e.g.:

“When the car blows up, the energy blows up; when the energy blows up, it spreads out.”

A9.6.4.2 ‘Energy escapes I’ - ‘Energy is stored I’

In the fourth interview, a month later, the introduction of the second set of pictures showing energy escaping and being stored due to chemical potential differences (see next section - A9.6.5), seems to have affected negatively the use of the pictures in question, now re-labelled as ‘energy escapes I’ and ‘energy is stored I’. Whereas for the simplest of all the changes presented to them in that interview, namely for ‘a hot bath cools down’, the pupils explained accurately and effortlessly that the appropriate match is ‘energy escapes I’

“...because first it’s hot and then it gets to the temperature of the room...”

in most other uses of the pictures the pupils did not attempt to link them with a temperature change. They rather seemed to choose them on the basis of the direction of the energy flow in them and by responding to the verbal prompts in their labels. The change of shading was freely interpreted as energy becoming more or less concentrated but not necessarily as something becoming warmer or colder. For example, one pupil matched the situation ‘charging a car battery’ to ‘energy is stored I’ and said:

“...when it gets recharged, the energy comes back, that’s why it’s more darker, the box is more darker than the outside.”

Another pupil, went even further and having matched the change ‘wood burning’ to the picture ‘energy escapes I’, said about it:

“That one, first it’s wood and then it goes and mixes with the air and it goes the same.”

In other words, he interpreted the picture as showing two different substances mixing.

Having said this, I have no doubt that the pupils could also read the conventions of the pictures in the way intended. The rejection of the match of the change ‘ice forming on a pond’ to the picture ‘energy escapes I’ was ironically based on a very extended, though not very clear, discussion of how ice and water do not end up at the same temperature.

A9.6.5 Stores of concentrated energy and energy flows

‘Energy escapes II’ - ‘Energy is stored II’

Similarly to the first group of pupils examined and unlike group two, the pupils in the third group showed very few signs that they differentiated between the pictures ‘energy escapes I’ and ‘energy escapes II’ and correspondingly between pictures ‘energy is stored I’ and ‘energy is stored II’. They seemed to choose the pictures ‘energy escapes II’ and ‘energy is stored II’ as matches to some changes either when they did not perceive the change as caused by some temperature difference, or when they perceived the metaphor of the spring being stretched (or released) as a suitable analogue of what happened in the change.

For the situation ‘ice forming on a pond’ for example, in the following quotation a pupil asserted his choice of the picture ‘energy escapes II’ not directly, but by arguing that the picture ‘energy escapes I’ would be an unsuitable match for the change because:

“It can’t cool down, because these will never become the same temperature, is it?”

The use of the picture ‘energy escapes II’ was a little more desirable in connection to the situation ‘wood burning’, which the pupils had previously met (and talked about in these terms) in their lessons.

“Because the energy is escaping; it is like a spring... [...] The spring is like this yeah, stretched out. Then it burns and burns and burns...”

On the other hand, the metaphor of the spring being stretched or released did not work always as intended. In two occasions, in relation to the situations ‘a plant growing’ and ‘pulling a catapult to get ready to fire a stone’, there is evidence that some pupils conceived the metaphor very literally. Having said this however, it is also true that at least in the case of ‘a plant growing’ this misreading of the metaphor gave rise to an intense exchange between the pupils:

P1: *“...store the water, yes. Because the water is putting in there and it just doesn’t happen by itself - you put the water in there, so you stretch the thing, like stretching a string, so the thing is going...”*

P2: *“You don’t stretch it. How can you stretch a plant?”*

P1: *“... stretch like you stretch a spring. And this is stretching upwards like...”*

P2: *“You don’t stretch it, it just grows. Are you stretched when you grow?”*

P1: *“No.”*

P2: *“Yeah, you see?”*

P1: *“It’s like stretching - giving an example like.”*

Finally, again similarly to what has been said about the choices made by pupils of Group 1 and Group 2, almost all the situations (with the exception of ‘wood burning’) ultimately matched to the pictures ‘energy escapes II’ or ‘energy is stored II’ were also matched appropriately to the pictures ‘it happens by itself’ and ‘it needs something to make it happen’ respectively.

A9.6.6 Steady-state systems:

‘No energy change’ - ‘Energy stays concentrated’

Interestingly no pupil chose the picture ‘no energy change’ in the third interview. By design, it would have been an appropriate match for the change ‘smoke filling the air over a city’. One pupil matched this change instead to the picture ‘energy stays concentrated’ on the basis that *“nothing happens to the energy of the smoke”*. The change was eventually kept under the picture of ‘energy spreads out’ since the smoke was thought of as cooling down as it spreads out in the sky.

The picture ‘energy stays concentrated’ was chosen and kept for the situations ‘water vapour forms clouds and it rains’ and ‘your body staying warm on a cold day’. Although it is not an appropriate choice for the first situation, the pupils came up with some useful ideas as a result of this match. They perceived the situation as depicting the water cycle and reasoned:

“Thinking about the water cycle... the water here is turning round like that yeah... and energy is going in and energy coming out like that.”

If the situation in question was about the water cycle, one would consider such an account quite important and desirable.

Now, in the fourth interview the picture 'no energy change' was chosen and kept as a match for the situation 'acid rain eroding a stone statue'. In the supporting argument the pupil explicitly acknowledged the absence of both inward and outward flows of energy, but treated energy very much as a substance, equating it in parts with rain itself.

"...it [the statue] don't let energy in and it don't let energy out. It just goes on it and it just slides down."

A9.6.7 Spontaneous and non-spontaneous change

A9.6.7.1 'It (just) happens by itself' - 'Someone makes it happen' - 'It needs something to make it happen'

The issues raised by the use the pupils of Group 3 made of the above phrases and/or abstract pictures have been already discussed in the corresponding analyses of the first and second groups of pupils' interviews (see sections 9.3.7 and A9.5.7). The progress in this case as well was subtle but gave the impression that it was in a desirable direction.

In the fourth interview the abstract picture 'it just happens by itself' was chosen in relation to the situations 'a plant growing', 'acid rain eroding a stone statue', 'ice forming on a pond' and 'a hot bath cools down'. In the case of the last two changes in particular it was considered the right match by all four pupils straight away. The other two situations in addition to the situations 'running and using up food', 'charging a car battery', 'wood burning' and 'pulling a catapult to get ready to fire a stone' were finally matched to the picture 'it needs something to make it happen'. The justifications the pupils offered for the match of 'running and using up food' to this picture explicitly acknowledged that 'energy escapes' in this change, but saw a need for this out-flow of energy to be triggered or even caused by an event (in this case by the person running). At the same time the pupils also acknowledged that *"you have to do something to get your energy back"* without perceiving any contradiction between the two assertions.

The match of the change 'acid rain eroding a stone statue' produced long and elaborate explanations. The focus however was not on the process of erosion and whether this is spontaneous or not, but rather on the process of the creation of acid rain; and since the existence of the reactants was considered a result of purposeful human action the process itself was judged to be non-spontaneous.

Finally, the discussion of the change 'wood burning' also produced interesting arguments. The pupils identified the need for the reactants (wood and oxygen) to exist in the first place and for a constant supply of them to exist thereafter if the process of burning is to be maintained. As a consequence they favoured matching the change to the picture 'it needs something to make it happen'. However, one pupil also considered the possibility of it being a spontaneous change and concluded that the change *"goes in the middle, between both"*, i.e. between the two abstract pictures.

A9.6.7.2 'It is easy to reverse the change'

Considering the use of the phrase 'it is easy to reverse the change', the pupils reasoned in similar ways to the pupils in the other groups. They mostly judged whether it is easy or not to reverse a change on the basis of whether they considered the reverse change possible or not. An interesting exception of this was met in the fourth interview for the situation 'charging a car battery'. There the pupils explicitly differentiated 'possible' from 'easier'; using the latter in the sense of 'costing less'!

"You don't need no money for the energy to go out, you need money to put the energy in."

Comparing to pupils of previous groups, one could maintain that these pupils seemed a little more sensitive in preserving the identity of the participants in a change when they considered its reversal. Perhaps the most interesting instance of this was when they considered reversing the change 'wood burning'; the following exchange took place:

P1: *"...you can get the same wood -similar like this -, but it won't be that wood you burn."*

P2: *"The main bits of it won't be the same."*

The second pupil indeed seems to be conserving the identity of the wood at the substance level.

Appendix 9.7

Comparison of explanations given by the Year 8 pupils of Group 1 for situations that appear in more than one interview

A9.7.1 Situations ‘a hot bath cools down’ and ‘ice forming on a pond’

These situations appear in the first (A) and the last (D) set of interviews; changes similar to these were discussed in the topic ‘Energy’.

The prompts used in both interviews for their discussion were: ‘it just happens by itself’ and ‘it is easy to reverse the change’. Also, the phrases ‘something gets colder or less hot’, ‘something gets warmer’, ‘temperature evens out’, ‘energy spreads out’ and ‘energy becomes concentrated in something’, used in the first interview, can be thought of as equivalent to the pictures ‘energy escapes I’ and ‘energy is stored I’ used in the last interview.

The pupils’ account of ‘a hot bath cools down’ was almost identical in both interviews. Energy was seen as residing in the hot water and coming out as the water cools down. In neither account was there any mention of the surroundings and/or its temperature, or of the temperature of the system at equilibrium. Moreover, the change was described as ‘happening by itself’ right from the first interview.

As for the situation ‘ice forming on a pond’, which is again a physical change, but rather less obvious as it combines a temperature change with a change of state, the pupils’ accounts seemed more sophisticated in the last interview. Whereas in the first interview the pupils did not pick any of the phrases that made reference to the temperature and energy change involved in the situation (i.e. ‘something gets colder or less hot’, ‘something gets warmer’, ‘temperature evens out’, ‘energy spreads out’ and ‘energy becomes concentrated in something’) as true descriptions of it, in the last interview they identified that energy is flowing out of the pond, and they linked this flow, however weakly, to the formation of ice. The change was seen as ‘happening by itself’. As before there was no mention of the surroundings and/or its temperature.

It is safe to assume that both these physical changes had been met by the pupils on different occasions in their Year 7 science lessons, if not in their primary science lessons, and thus in their accounts of them one could not expect to see drastic shifts.

A9.7.2 Situations ‘acid rain eroding a stone statue’ and ‘wood burning’

These situations appear in the first (A) and the last (D) set of interviews; changes similar to these were discussed in the topic ‘Substances’.

The prompts used for the discussion were the same as for the previous two situations.

The pupils’ accounts for the situation ‘acid rain eroding a stone statue’ hold limited interest, since in both interviews they focused on the material changes that it involves and ignored the possible energy changes that could accompany them. In the fourth interview the situation was matched by all four pupils to the ‘no energy change’ picture. One could have expected this, as this situation had been met by the pupils in the topic ‘Substances’ which dealt with chemical reactions as substance changes and not as energy changes. Having said this, it is worth noticing that not much progress was observed in the pupils’ accounts of the material changes either. In the first interview the acid rain was said to be mixing with the stone statue and no change of substance was said to happen, and in the last “*the acid rain touches the stone statue and the chemicals in the acid rain are making the stone statue dissolve*”.

The difficulty the pupils faced in distinguishing between the physical and chemical changes has been reported and elaborated in the pupil case studies (section 8.4).

'Wood burning' on the other hand was a situation that produced interesting discussions especially in the last interview. There the first question that seemed to divide the pupils was whether energy is going in or out in when wood is burning. In the first interview it was clear for them that energy - whether this was the "*energy of the fire*" or the "*energy of the wood*" - spreads out:

"The energy of the fire spreads out and eventually it dies out. All the energy is going. The energy is the wood. The wood begins to fade, begins to get shorter and energy fades away."

In the last interview, however, things did not seem so straightforward. Now they knew that oxygen, or 'air' as they said, is also needed for burning, energy is not the wood only:

P: *"You get wood yeah, you burn it, then you put a glass thing over it it's going to stop burning, it's just going to stop. Because there's no air getting into it. You have to let air get into first."*

P: *"Yes, there's energy going in."*

Moreover, understandably fire was also perceived as a source of energy which "*is going inside the wood and is making the wood burn away*". So, whereas there was still consensus that energy is going out, they also recognised that "*you need the energy to go in before the energy goes out*".

The appreciation of the need for air and fire for the wood to burn also inhibited some of them to reason that the change is a spontaneous one. The majority of the pupils though still agreed that once the necessary participants (wood and air) exist and the wood is lit, the change 'just happens by itself'.

About whether 'it is easy to reverse the change' both in the first and last interview the idea expressed was that it is not easy to reverse 'wood burning'; instead suggestions were offered for how one could repeat the change by burning another piece of wood.

A9.7.3 Situation 'a plant growing'

This situation appears in the first (A) and the last (D) set of interviews; no change similar to this was discussed in the Year 8 class, although one could see how the ideas introduced in the topic 'Food and Fuels' are pertinent for the description of this change.

The prompts used for its discussion were the same as for the other situations with the exception of the phrase 'it is easy to reverse the change', which was not used in the last interview in relation to this situation.

In both interviews we expected pupils to know very little about the chemical changes involved in a plant growing; and indeed they focused more on what they were substantially more familiar with, that is the conditions needed for a plant to grow. In the first interview the focus was on the sun; the sun was seen as more than an energy source, it was seen as energy itself and thus they reasoned that energy spreads out since "*the sun spreads out over the thing [plant]*". In the last interview all the pupils seemed to agree that energy gets stored when a plant grows, but were not sure about how this worked.

Finally in both interviews 'a plant growing' was said 'to need something to make it happen'. Unfortunately this 'something' was not identified to be another spontaneous change; in the first interview it was said to be the action of 'watering' - "*someone has to water it to make it grow*" -, and in the last it was said to be water and sun. However, one pupil in the last interview also acknowledged in passing that "*it needs energy for it to grow, it can't just happen by itself*". Although still far from

what would be considered a desirable account of non-spontaneity from the project's point of view it seems potentially more useful and relevant than the others.

Summing up, there was no substantial progress in the children's account of a plant growing. This was rather expected since neither this change, nor similar ones were examined by the materials used in Year 8 - the process of photosynthesis is not addressed until Year 9. However, this would not necessarily have been the case, if the pupils had been taught in Year 7 that the process of growing is one of 'bunching together', as the Year 7 pupils in this research were. One would imagine that some knowledge of what happens to matter in a 'growing' change might have helped pupils to at least make some assumptions about what happens to the accompanying energy.